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TEC
GUIDANCE FOR STUDENTS

Contents

TECHNICIAN EDUCATION COUNCIL

Certificate Programme in Telecommunications

Sets of model questions and answers for Technician Education Council (TEC) units are given below. The questions illustrate the types of questions that students may encounter, and are useful as practice material for the skills learned during the course.

Where additional text is given for educational purposes, it is shown within square brackets to distinguish it from information expected of students under examination conditions. Representative time limits are shown for each question, and care has been taken to give model answers that reflect these limits.

We would like to emphasise that the questions are not representative of questions set by any particular college.

TEC: MICRO-ELECTRONIC SYSTEMS I

The questions in this paper are based on the TEC's standard unit U79/602. Students are advised to read the notes on p. 1

Q1 What are the 3 essential parts of a system? *(2 min)*

A1 Input, process and output.

Q2 Analyse a coffee percolator as a system. *(3 min)*

A2 The inputs to a coffee percolator are water, coffee and electricity. The process involves using the electricity to boil the water and thereby cause the water to flow through the coffee. The output is hot coffee.

Q3 Is it reasonable to consider a small shop as a system? Explain your answer. *(3 min)*

A3 Yes. There are inputs such as goods to sell, services (for example, electricity and water) and labour. The process is the selling of goods and the outputs are the goods sold.

Q4 An electric heater is controlled by a thermostat. Explain this in systems terms. *(4 min)*

A4 The system consists of the heater and thermostat. The inputs to the system are electricity and the temperature of the room. According to the temperature, the thermostat either switches the heater ON or OFF, and, when ON, the heater processes its supply of electricity. The output is heat in the room.

Q5 What is a transducer? *(3 min)*

A5 A transducer is a device for converting one form of energy into another.

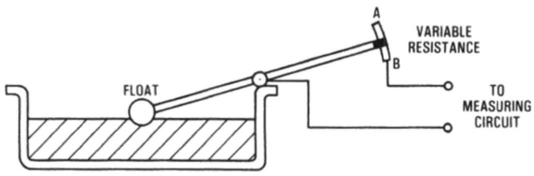
Q6 Give 3 examples of transducers and indicate their function. *(3 min)*

A6 Examples are:

(*a*) a microphone, which converts sound energy into electrical signals;
(*b*) a light bulb, which converts electrical energy into light energy; and
(*c*) a thermistor, which converts heat energy into electrical signals.

Q7 Draw a diagram of a liquid-level transducer. *(5 min)*

A7



Q8 What is a block diagram? *(3 min)*

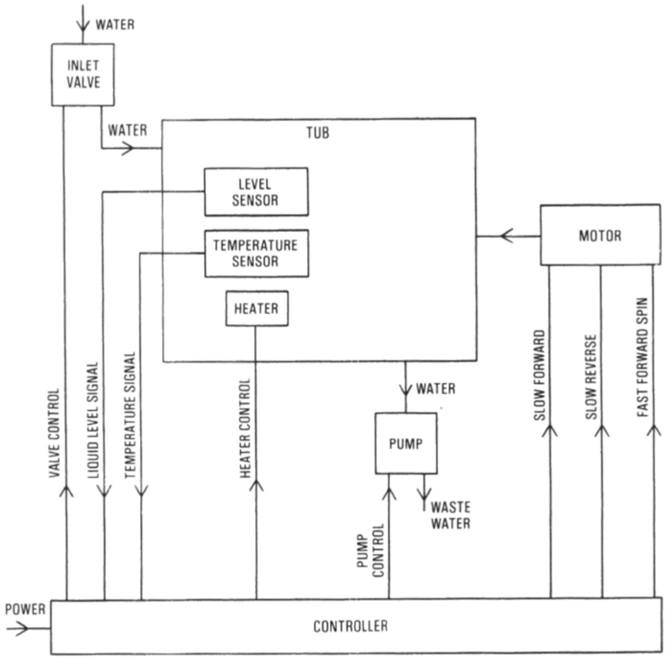
A8 A block diagram is a diagram that shows the different parts of a system represented by blocks and the paths of logical interconnections between them. A block diagram does not physically represent the actual system as a schematic diagram would.

Q9 In the context of an automatic washing machine, what is meant by the term program? *(3 min)*

A9 An automatic program for a washing machine is the sequence of operations that the machine follows in a complete washing cycle.

Q10 Draw a block diagram of a domestic automatic washing machine. (*10 min*)

A10



Q11 What do you understand by the term 'controller' in terms of an automatic washing machine? (*5 min*)

A11 The controller in an automatic washing machine is one of many subsystems (such as, motors, heater, temperature sensors, etc.) the function of which is to control the operation of all the other subsystems in a predetermined sequence.

Q12 Compare critically the 2 fundamentally different types of controllers used in domestic automatic washing machines. (*8 min*)

A12 The 2 different types of controllers used are

(*a*) an electromechanical system, and
(*b*) a microprocessor-based system.

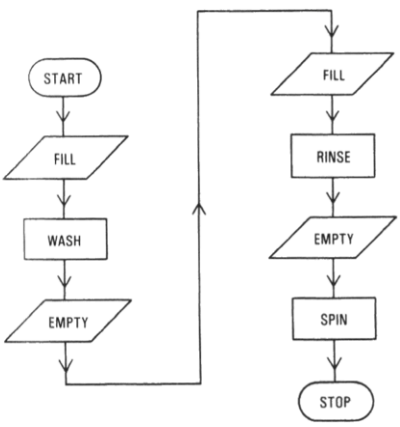
The electromechanical type has possibly hundreds of moving parts and, therefore, is susceptible to mechanical wear. The microprocessor-based type has no moving parts, being entirely based on solid-state electronics, and is potentially more reliable.

Q13 Write a typical sequence of operations that an automatic washing machine might follow. (*5 min*)

A13 Start, fill, wash, empty, fill, rinse, empty, spin, stop.

Q14 Take your answer to Q13, and draw a flow chart to represent the sequence of operations. (*10 min*)

A14



Q15 Explain the terms 'analogue' and 'digital' as used in the context of micro-electronic systems. (*5 min*)

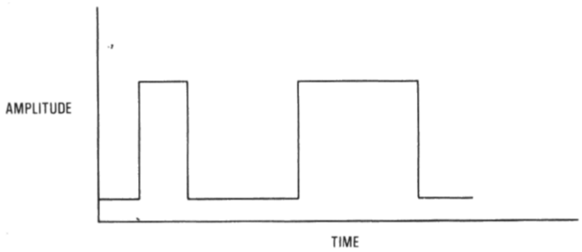
A15 *Analogue* refers to a quantity that can change continuously with time, and, therefore, can have any value at any one time. *Digital* quantities, on the other hand, are discontinuous in time, and have a finite number of discrete states between which instantaneous transitions can take place.

Q16 How many states does a binary digital system have? (*2 min*)

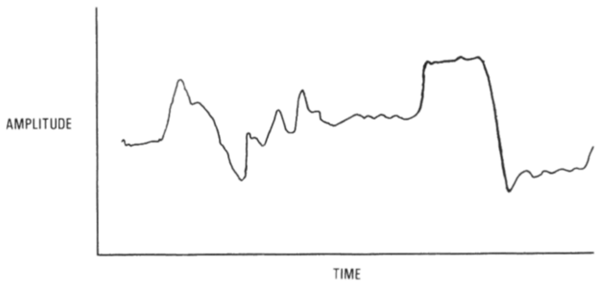
A16 2

Q17 The 2 diagrams, (i) and (ii), given below show variations of electronic signals against time.

(*a*) *Which diagram represents a digital signal?*
(*b*) *Which diagram represents a continuous signal?*
(*c*) *Which diagram might represent signals in a microprocessor?* (*3 min*)



(*i*)



(*ii*)

A17 (*a*) (*i*).
(*b*) (*ii*).
(*c*) (*i*).

Q18 What is an analogue-to-digital converter? (*8 min*)

A18 Many transducers generate analogue signals, yet micro-electronic systems require digital inputs. Therefore, devices known as analogue-to-digital converters are used to digitise an analogue input. These devices, normally available as a single chip, take an input of an analogue signal, between 0 and 5 V, and produce a binary output, often of 8 bits (that is, a numerical value in the range 0 to 255).

Q19 Give an example of an analogue system, with a brief explanation. (*5 min*)

A19 A hi-fi amplifier is a typical analogue system, where a small analogue input generates a large analogue output to loudspeakers. Clearly, the power signal to the loudspeakers must be continuously variable, both in level and frequency.

Q20 Give an example of a digital system, with a brief explanation. (*5 min*)

A20 A digital watch is a typical example, where vibrations of a quartz crystal are counted by a micro-electronic circuit and processed for output through a digital display.

Q21 How is information represented internally in a digital system? (*5 min*)

A21 Digital signals normally have two states, typically 0 and 5 V. These states can also be referred to as *logic 0* and *1*, *OFF* and *ON*, or *FALSE* and *TRUE*. One individual digital signal is known as a *b*inary dig*it* or *bit*. A group of 8 bits is known as a *byte*.

Q22 What is ASCII code? *(5 min)*

A22 ASCII stands for the *American Standard Code for Information Interchange*, a system of coding letters, numbers and symbols into 7 or 8 bit numbers for convenient representation in digital systems.

Q23 What is a discrete-component electronic circuit? *(5 min)*

A23 A discrete-component electronic circuit is a circuit that is made up from a collection of resistors, capacitors, transistors etc., soldered together and probably mounted on some kind of circuit board.

Q24 What is an integrated circuit? *(5 min)*

A24 An integrated circuit is a single electronic component, often referred to as a *chip*, which can have many connections to it, but which contains, in a miniaturised form, the equivalent of all the separate components in a discrete-component circuit.

Q25 What do the terms

(a) SSI,
(b) MSI,
(c) LSI, and
(d) VLSI.

mean? *(1 min)*

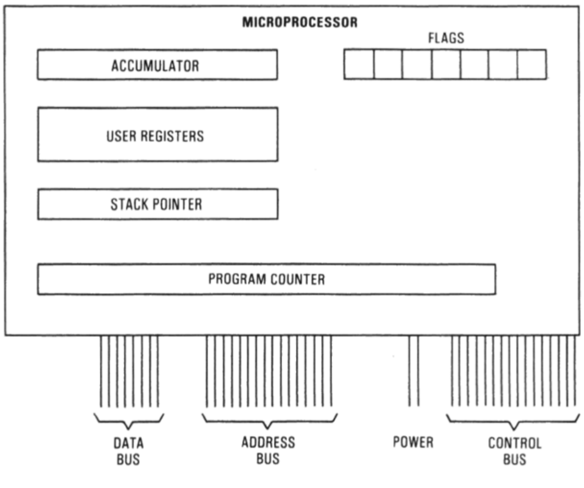
A25 (*a*) SSI stands for *small-scale integration*, and refers to integrated circuits that contain up to 10 device equivalents.
(*b*) MSI stands for *medium-scale integration* and refers to integrated circuits that contain between 10 and 100 device equivalents.
(*c*) LSI stands for *large-scale integration* and refers to integrated circuits that contain between 100 and 1000 device equivalents.
(*d*) VLSI stands for *very-large-scale integration* and refers to integrated circuits that contain more than 1000, and, currently, up to about 100 000 device equivalents.

Q26 What type of integrated circuit is a microprocessor? *(3 min)*

A26 A microprocessor is a VLSI device.

Q27 Draw a simple block diagram of a microprocessor. *(10 min)*

A27



Q28 What, in terms of a microprocessor system, is a peripheral? *(3 min)*

A28 A peripheral is a device that enables the microprocessor system to communicate with the outside world.

Q29 Give 2 examples of peripherals and explain briefly their function. *(6 min)*

A29 Two examples are:

(*a*) *Visual display unit* (*VDU*) This is a device to enable people to communicate with microprocessor systems. A keyboard is provided for input by the operator, and a screen for output from the microprocessor.
(*b*) *Magnetic disc drive* This is a data storage device which records data on, and replays data from, a flat disc with a magnetic coating.

Q30 Differentiate between the following terms: hardware, software, and firmware. *(3 min)*

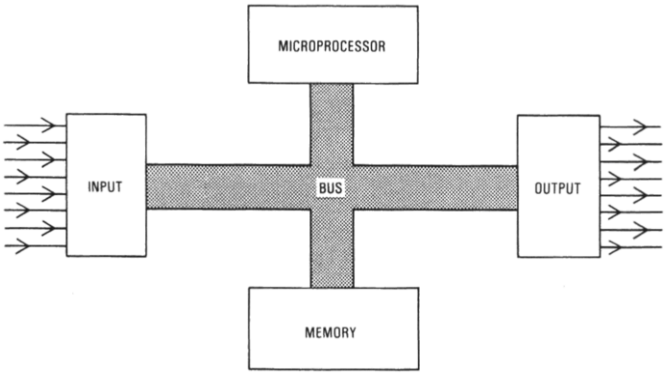
A30 Hardware is the physical parts of a microprocessor system. Firmware and software are programs that run on the hardware, firmware being the permanent systems software, and software the user's programs.

Q31 How is a microprocessor instructed to perform a series of tasks? *(3 min)*

A31 Microprocessors obey a series of instructions called a *program*, which is stored within the system as a series of numbers.

Q32 A typical microcomputer system consists of a microprocessor, a memory and input/output facilities. Draw a diagram to illustrate the overall system containing these components. *(8 min)*

A32



Q33 Would fixed or changeable storage be used for user's programs? *(2 min)*

A33 Changeable, since programs often need to be changed and edited.

Q34 Explain the terms 'read-only memory' and 'random-access memory'. *(5 min)*

A34 *Read-only memory* (ROM) is a fixed type of storage device, whose contents cannot be altered by the user, but can be read by the microprocessor. This type of device is used for firmware storage.
Random-access memory (RAM) is a changeable type of storage device that allows the user either to read existing contents or to write new ones. This type of device is used for software and data storage.

Q35 Explain the terms 'volatile' and 'non-volatile' as applied to random-access memory (RAM). *(5 min)*

A35 The contents of a volatile RAM are lost when power to the system is switched off. A non-volatile RAM has a back-up system whereby the system can be switched off without the contents of the memory being lost.

Questions 36–39 refer to an imaginary microprocessor with the following specification.

[*Tutorial note:* The following questions are concerned with microprocessor programming. In practice, several different microprocessors are available, all of which use different sets of instructions. For the purpose of illustrating the principles involved an imaginary device has been created.]

The device operates on 8 bits of data, with 16 bit memory addresses. It contains two 8 bit registers for the programmer's use: the accumulator (A) and the count register (C). Some of the fundamental instructions recognised by the device are given in the following table.

Instruction	Hexadecimal Code
Load A with the next byte of data	52
Store the value in A in the memory location represented by the following 2 bytes of data	9A
Store the value in A to C	9C
Add the next byte of data to A	6B
Decrement A by one	AA
Decrement C by one	AC
Halt execution	F4
Jump unconditionally to the memory location represented by the following 2 bytes of data	12
Compare A with the next byte of data	7A
Compare C with the next byte of data	7C
If the 2 bytes of data compared are equal, jump to the memory location represented by the next 2 bytes of data	EE

Q36 A program for the imaginary microprocessor is shown below. Dry run the program, and state the contents of registers A and C, and memory location 1020, at the end of the program.

Address	*Hexadecimal Code*
1000	*52 05*
1002	*9C*
1003	*52 10*
1005	*AA*
1006	*AC*
1007	*9A 10 20*
100A	*F4*

(10 min)

A36 Register A contains 09 hex, register C contains 04 hex, and memory location 1020 contains 09 hex.

Q37 Write a program using the instruction set given, to add 2 and 3, and store the result in memory location 1020. (Start at address 1000.) *(10 min)*

A37

Address	Hexadecimal Code
1000	52 02
1002	6B 03
1004	9A 10 20
1007	F4

Q38 Dry run the program given in the following table and state the contents of registers A and C at the end of the program.

Address	*Hexadecimal Code*
1000	*52 68*
1002	*12 10 07*
1005	*52 00*
1007	*6B 4B*
1009	*F4*

A38 Register A contains B3, and register C contains an undefined value.

Q39 Write a program, using the instruction set given, to multiply 5 by 8 (that is, add 5 to itself 8 times), and store the result in memory location 1020. (Start at address 1000.) *(15 min)*

A39

Address	Hexadecimal Code
1000	52 08
1002	9C
1003	52 00
1004	6B 05
1006	AC
1007	7C 00
1009	EE 10 13
100F	12 10 04
100C	9A 10 20
100F	F4

Questions and answers contributed by P. Byass

TEC: LINE AND CUSTOMER APPARATUS I

The questions in this paper are based on the TEC's standard unit U81/749. Students are advised to read the notes on p. 1

Students should allow about 6 min for each question in Section A and 20 min for each question in Section B.

SECTION A

Q1 Suggest the appropriate telephone facilities for the following situations:

(a) a family living in a semi-detached house expecting to receive calls at any time, day or night.

(b) a large manufacturing firm that has a high calling rate and the need for efficient internal communications between a large number of extensions.

A1 (*a*) A main telephone in the hall or lounge, and an extension telephone at the bedside in the main bedroom.

(*b*) A PABX with a number of operator positions sufficient to handle the incoming, and, when necessary, the outgoing traffic.

Q2 At the beginning of a call, a customer's meter reading is 07863. At the end of a call lasting 7 min the reading is 07933.

(a) If each unit is charged at 4·5p, calculate the total cost of the call.

(b) Calculate the charge rate; that is, the time allowed per unit.

A2

Meter reading at the end	07933
Meter reading at the beginning	07863
Number of meter units	70

(*a*) Total cost = 4·5 × 70 = 315p = £3·15.

(*b*) Duration of the call = 7 mins,
= 7 × 60 = 420 s.

$$\text{Charge rate} = \frac{\text{duration of the call}}{\text{meter units}} = \frac{420}{70} = 6\ \text{s},$$

that is, the time allowed for 1 unit is 6 s.

*Q3 (a) Delete the incorrect numbers (at the points marked *):*

In a keypad sending multi-frequency (MF) tones, depressing a key transmits 2/4/10 tones to line. Each oscillator which produces the tones has 4/10/16* different output frequencies.*

(b) State two advantages of a keypad.

A3 (*a*) In a keypad sending multi-frequency (MF) tones, depressing a key transmits two tones to line. Each oscillator which produces the tones has four different output frequencies.

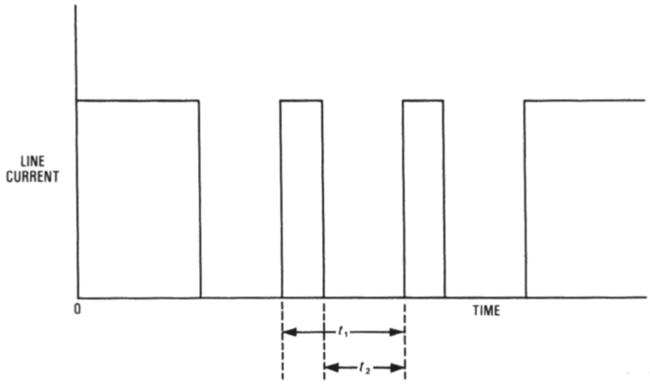
(*b*) The advantages of a keypad are:

(*i*) the fact that it is faster and easier for a customer to operate; and

(*ii*) the fast signalling facility, and resultant fast connection, when used with certain common-control systems (not for loop-disconnect signalling).

Q4 The diagram below shows the current in a telephone line as a digit is dialled.

(a) What digit has been dialled?
(b) State the times represented by t_1 and t_2, assuming that the dial pulses are at the nominal speed and ratio.



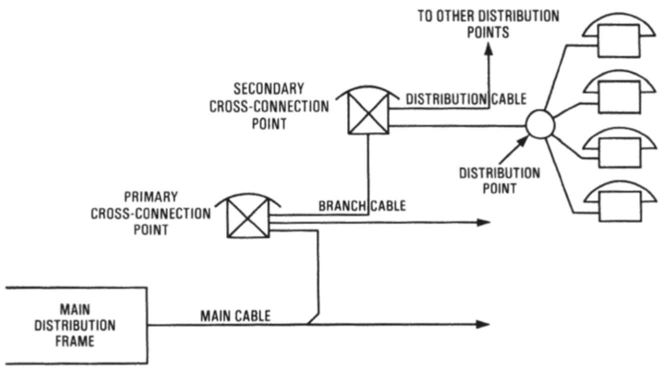
A4 (*a*) The diagram given in the question shows 3 *break* pulses in the train, therefore the digit 3 has been dialled.
(*b*) Assuming the dial speed is at 10 pulses/s and the ratio at 2 : 1 (break : make), then

$$t_1 = \underline{100 \text{ ms}},$$

$$\text{and } t_2 = \underline{67 \text{ ms}}.$$

Q5 The local cable network in a small area is shown below.

(a) Why is flexibility necessary in the local cable network?
(b) How is flexibility introduced?



A5 (*a*) Flexibility is necessary in the local cable network to ensure that plant is available to meet demands for service, and to meet inaccuracies in the forecasts by rearranging plant at minimum cost.
(*b*) Flexibility is obtained by using main, branch and distribution cables, together with flexibility points:

(*i*) the main distribution frame at the telephone exchange,
(*ii*) primary cross-connection points,
(*iii*) secondary cross-connection points, and
(*iv*) distribution points.

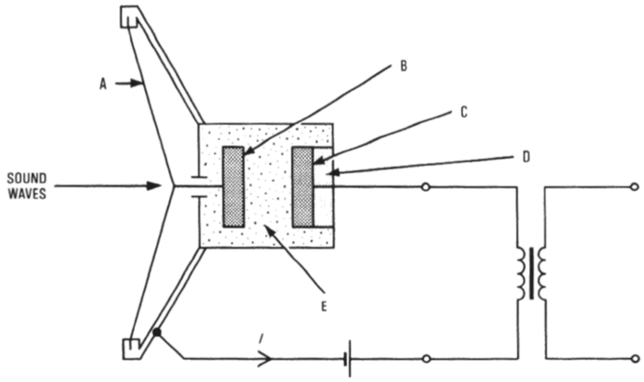
Q6 Show by writing A to indicate a pay-on-answer coinbox, or B to indicate a pre-payment coinbox, to which the following statements refer:

(a) It needs special calling equipment in the exchange.
(b) A tone is applied to indicate called party answer.
(c) The dial is ineffective until money is inserted.
(d) Speech is interrupted during coin-value signalling.
(e) It is convenient for high-tariff calls.

A6 (*a*) A
(*b*) A
(*c*) B
(*d*) A
(*e*) B

Q7 A simplified diagram of a carbon granule transmitter is shown below.

(a) Name the parts labelled A to E.
(b) Explain what happens to the current I when an increase in pressure moves the diaphragm inwards.



A7 (*a*) A Diaphragm
B Moving carbon electrode
C Fixed carbon electrode
D Insulation
E Carbon granules

(*b*) The resistance of the carbon granules decreases with an increase in pressure. Therefore the current *I* increases because of the decrease in resistance.

Q8 The chart given below shows a diagrammatic representation of the order in which a local cable project has to be carried out. Items of plant and materials, and some labour details, have been omitted. Complete the chart for this project.

	ACTIVITY	EXCAVATE TRENCH	INSTALL DUCT	FILL TRENCH	DRAW IN CABLE	JOINT CABLE	TEST CABLE
RESOURCES	PLANT						
	MATERIALS						
	LABOUR (PERSONS)	5	4	3	5		3

0 TIME

A8

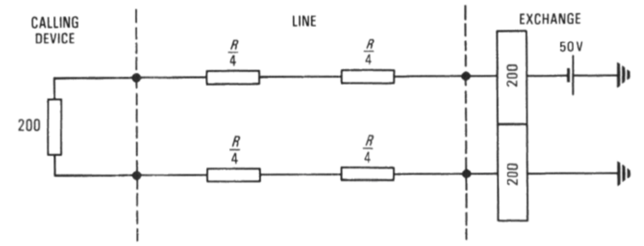
	ACTIVITY	EXCAVATE TRENCH	INSTALL DUCT	FILL TRENCH	DRAW IN CABLE	JOINT CABLE	TEST CABLE
RESOURCES	PLANT	EXCAVATOR			WINCH		
	MATERIALS		DUCT		CABLE		
	LABOUR (PERSONS)	5	4	3	5	(2)	3

0 TIME

Q9 The line relay for a particular system has a resistance of 400 Ω and requires a minimum current of 40 mA for satisfactory operation. Assuming that the calling device has a resistance of 200 Ω, and the system voltage is 50 V, determine the maximum length of line that is possible, if the cable to be used has a resistance of 100 Ω/km loop.

A9 The circuit is shown in the sketch.
The minimum current = 40 mA = 40×10^{-3} A.
The supply voltage = 50 V.
Therefore, the maximum total resistance

$$= \frac{50}{40 \times 10^{-3}} = 1250\ \Omega.$$



The maximum total resistance includes:

the relay resistance	400 Ω
the calling device resistance	200 Ω
total (less line resistance, R)	600 Ω

Therefore, the line resistance = 1250 − 600 = 650 Ω.
Therefore, the maximum length of line

$$= \frac{650}{100} = \underline{6{\cdot}5\text{ km.}}$$

Q10 The heaviest load that a manhole cover is expected to take is 25 t. State the load which the cover is built to withstand, and explain the answer.

A10 The manhole cover is designed for the heaviest traffic load likely to occur. The design loading is obtained by multiplying the expected loading by a safety factor. The safety factor is usually about 2, which in this case gives a design load of 25 × 2 = <u>50 t</u>; that is, the cover is designed to withstand double the heaviest load expected.

SECTION B

Q11 Name and briefly describe the following signals between the exchange and the customer on an automatically connected call.

(a) The caller sends a signal to the exchange to initiate a call.
(b) The exchange indicates to the caller the readiness to accept instructions.
(c) The customer's instructions pass to the exchange.
(d) The exchange indicates to the caller the state of the called line,

(i) assuming the called line is already making a call,
(ii) assuming the called number has not been allocated, and
(iii) assuming the called line is free.

(e) The exchange indicates that the call has been answered.
(f) The caller indicates to the exchange when the call is completed.

A11 (*a*) The caller lifts the telephone receiver and extends a calling loop to the exchange.
(*b*) Dial tone is returned to the caller to indicate the readiness of the exchange to accept instructions.
(*c*) Dial pulses are transmitted from the dial or keypad to the exchange.
(*d*) (*i*) If the called line is already engaged, then busy tone is returned to the caller.
(*ii*) If the called number is spare, then number-unobtainable tone is returned to the caller.
(*iii*) If the called line is free, then ringing tone is returned to the caller.
(*e*) When the called customer answers, ringing tone stops and conversation can begin.
(*f*) Call completion is indicated by the caller replacing his telephone receiver, and this disconnects the calling loop.

Q12 A PMBX cordless switchboard (not in current use) has:

4 exchange lines,
12 extensions,
1 operator circuit, and
5 connecting circuits.

The keys have three positions (centre position OFF*) arranged in the standard layout.*

(a) Calculate:

(i) the number of crosspoints, and
(ii) the number of keys.

(b) Draw a diagram showing the co-ordinate switching for this cordless switchboard.

A12 (*a*) (*i*) The number of crosspoints
= (number of exchange lines
+ number of extensions
+ number of operator circuits)
× number of connecting circuits,
= (4 + 12 + 1) × 5,
= <u>85.</u>

(*ii*) The total number of keys
= (number of exchange lines
+ number of extensions
+ number of operator circuits)
× number of keys per column of keys.

The number of keys per column

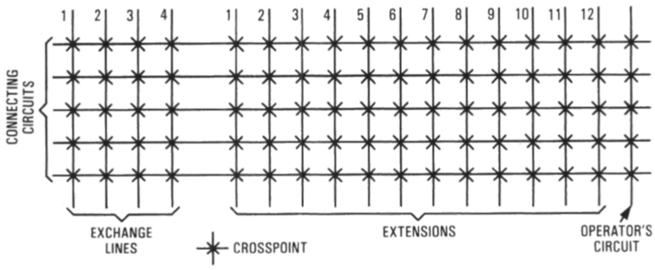
$$= \frac{\text{number of connecting circuits} + 1\text{ (ring circuit)}}{\text{number of circuits per key}},$$

$$= \frac{5+1}{3-1},$$

= 3.

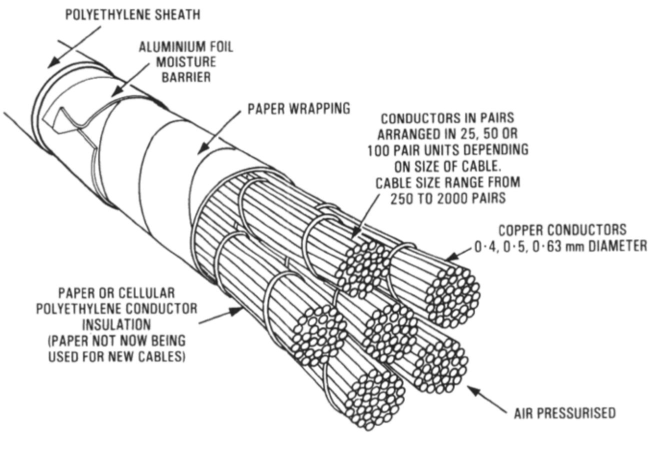
Therefore, the total number of keys
= (4 + 12 + 1) × 3,
= <u>51.</u>

(*b*)

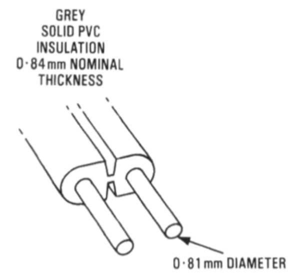


Q13 Various types of cables are shown below.

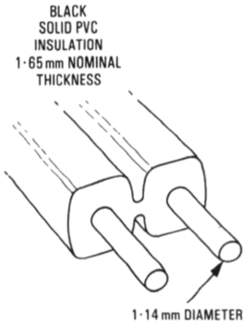
(a) Identify the cables.
(b) Draw a block diagram of a telecommunication network and show where each type of cable identified in part (a) may be used.



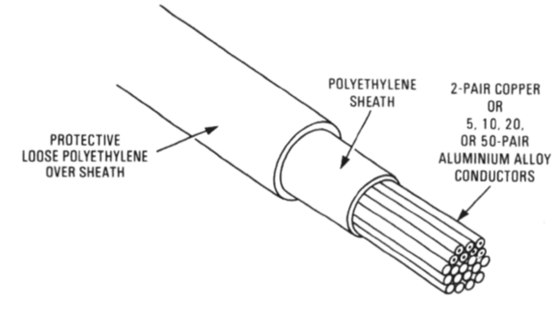
(*i*)



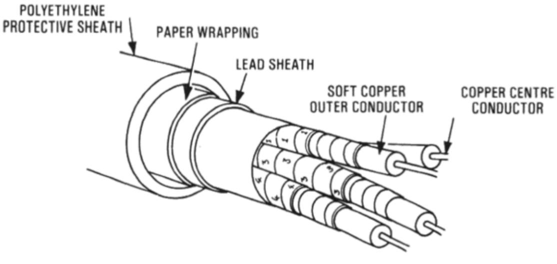
(*ii*)



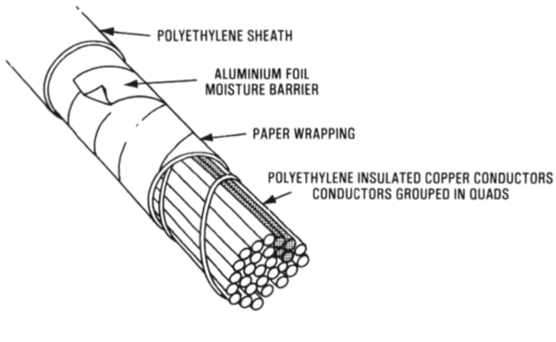
(*iii*)



(*iv*)



(*v*)



(*vi*)

A13 (*a*) (*i*) Local main distribution cable (installed between the exchange and primary distribution point).

(*ii*) Dropwire for general use. This is also used for power crossings and joint user on power-carrying poles up to 650 V (and under insulated power cable crossings up to 11 kV.)

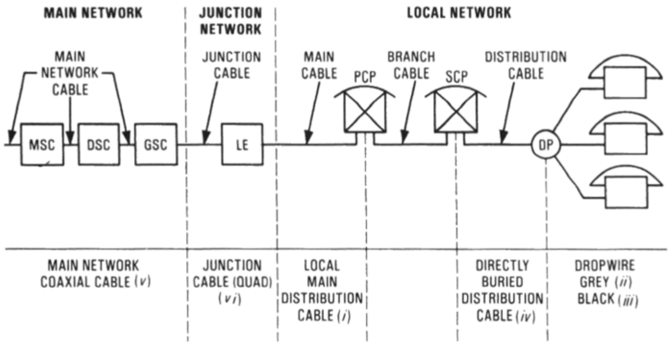
(*iii*) Dropwire for power crossings, and joint user on power-carrying poles above 650 V and below 11 kV (uninsulated).

(*iv*) Directly buried distribution cable.

(*v*) Coaxial cable (used for the long distance or main network).

(*vi*) Quad-formation junction cable.

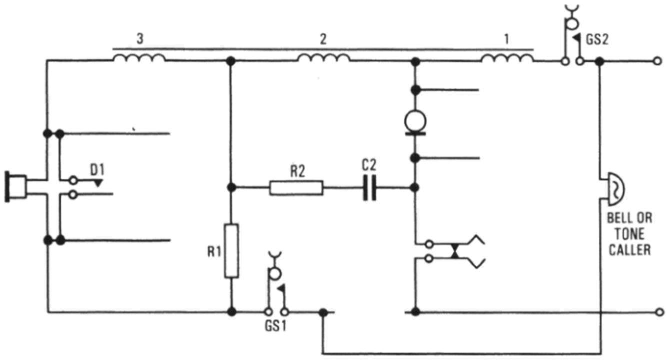
(*b*)



Q14 (*a*) *Explain the need for a regulator in a telephone instrument.*

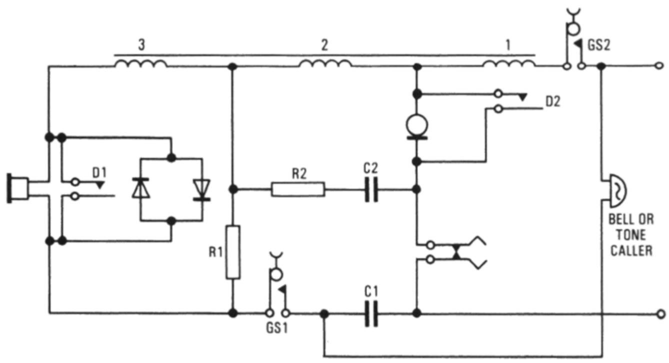
(*b*) *A simplified circuit of a telephone instrument, without the regulator, is shown below. Three items have been omitted from the diagram. Draw the circuit diagram including the missing items.*

(*c*) *Explain the function of the three missing items.*



A14 (*a*) Telephone instruments are required to work satisfactorily over varying line lengths. The loop resistance of a customer living close to the exchange is less than that of a customer at the exchange boundary. More current flows in telephones near to the exchange, making them more sensitive than those in outlying places, and, therefore, some form of regulation is desirable. The telephone is designed to work satisfactorily on a long line, with the regulator almost ineffective. However, on shorter lines the regulator reduces the sensitivity of the telephone instrument, otherwise the signals to and from the instrument would be considered to be too loud.

(*b*)



(*c*) The functions of the missing items are as follows:

(*i*) The diodes across the receiver suppress any surge voltages which could cause acoustic shock; for example dialling clicks.

(*ii*) The dial off-normal springs D2 short circuit the transmitter during dialling, thus presenting a low resistance loop condition to line.

(*iii*) Capacitor C1 is effectively connected in series with the bell, and allows the passage of ringing current (AC). The DC loop is not extended to the line until the handset is lifted. Capacitor C1, together with capacitor C2 and resistor R2, forms a spark quench circuit for the dial pulsing contacts.

Questions and answers contributed by R. Wilson

The questions in this paper are based on the TEC's standard unit U81/750. Students are advised to read the notes on p. 1

Q1 *Convert the following denary numbers to their binary equivalents:*

(*a*) *22·625, and*
(*b*) *250.* (*5 min*)

A1 The denary numbers are converted to binary form by repeatedly dividing the integral part by 2 and multiplying the fractional part by 2 as shown in the following tables:

(*a*)

Integral Part	
Quotient	Remainder
2)22	
11	0
5	1
2	1
1	0
0	1 (most significant bit)

Fractional Part	
Result	Product
	·625 × 2
1	·250
0	·500
1	·000

Hence, $22{\cdot}625_{10} = \underline{10\,110{\cdot}101_2}$.

(*b*)

Quotient	Remainder
2)250	
125	0
62	1
31	0
15	1
7	1
3	1
1	1
0	1

Hence, $250_{10} = \underline{11\,111\,010_2}$.

Q2 *Convert the following binary numbers to their denary equivalent:*

(*a*) *10010·011, and*
(*b*) *0·110 11.* (*5 min*)

A2 The conversion is performed by multiplying each binary digit by its 'weight' and summing the results.

(*a*)

$$\begin{array}{cccccccc} 1 & 0 & 0 & 1 & 0\cdot & 0 & 1 & 1 \\ \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \end{array}$$

$$(1 \times 16) + (0) + (0) + (1 \times 2) + (0) + (0) + (1 \times 0{\cdot}25) + (1 \times 0{\cdot}125)$$

$$= \underline{18{\cdot}325_{10}}.$$

(*b*)

$$\begin{array}{cccccc} 0 & 1 & 1 & 0 & 1 & 1 \\ \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \end{array}$$

$$(0) + (1 \times 0{\cdot}5) + (1 \times 0{\cdot}25) + (0) + (1 \times 0{\cdot}0625) + (1 \times 0{\cdot}03125)$$

$$= \underline{0{\cdot}843\,75_{10}}.$$

Q3 *Write down the denary equivalent of the following binary numbers, which are written in two's complement notation:*

(*a*) *01 100 010,*
(*b*) *10 000 000, and*
(*c*) *11 111 111.* (*6 min*)

A3 [*Tutorial note:* In two's complement notation, the most significant bit (bit 7 in the examples) represents the sign of the number: 0 for positive and 1 for negative.]

(*a*) This is a positive number since bit 7 is 0.

$$\begin{array}{cccccccc} 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 \\ & \downarrow & \downarrow & & & & \downarrow & \end{array}$$

$$(1 \times 64) + (1 \times 32) + (1 \times 2)$$

$$= 98.$$

Therefore, the denary equivalent = $\underline{+98.}$

(*b*) This is a negative number since bit 7 is a 1. Its value is calculated by finding the two's complement and converting the result to a denary number, as follows:

Number:	10 000 000
Invert:	01 111 111
Add 1:	1
	10 000 000

$$\downarrow$$

$$(1 \times 128) = 128.$$

Therefore, the denary equivalent = $\underline{-128.}$

(*c*) Similarly to part (*b*):

Number:	11 111 111
Invert:	00 000 000
Add 1:	1
	00 000 001

$$\downarrow$$

$$(1 \times 1) = 1.$$

Therefore, the equivalent denary number = $\underline{-1.}$

Q4 *Determine the value of*

$$1011011{\cdot}101 + 1\,100001{\cdot}011,$$

and give the answer in denary form. (*4 min*)

A4

```
        1 011 011·101
        1 100 001·011 +
Carry   1     111 11
       10 111 101·000
```

This is converted into denary form as follows:

$$\begin{array}{cccccccc} 1 & 0 & 1 & 1 & 1 & 1 & 0 & 1 \\ \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \end{array}$$

$$(1 \times 128) + (0) + (1 \times 32) + (1 \times 16) + (1 \times 8) + (1 \times 4) + (0) + (1 \times 1)$$

$$= \underline{189_{10}}.$$

Q5 *Subtract 100 111 from 110 000 by using the method of complement addition. Check your answer in decimal.* (*4 min*)

A5 First find the two's complement of $100\,111_2$.

Invert:	011 000
Add 1:	1
	011 001

Then add 110 000.

```
          110 000
          011 001
Carry     1
        1 001 001
```

The overflow 1 indicates a positive result: $\underline{+001\,001}$ (decimal 9).
In decimal,

$$110\,000 = 48, \text{ and}$$

$$100\,111 = 39.$$

Thus,

$$48 - 39 = \underline{9}, \text{ as before.}$$

Q6 The three inputs of a NAND *gate are A, B and C. Which of the following represents the output?*

(*a*) $A + B + C$
(*b*) $A.B.C$
(*c*) $\overline{A.B.C}$
(*d*) $\overline{A}.\overline{B}.\overline{C}$

(1 min)

A6 (*c*) $\overline{A.B.C}$

Q7 Complete the sentence below with one of the four answers given.

'The type of gate whose output is a logic 1 when one or more of its inputs are at logic 1 is a 3-input . . . gate.'

(*a*) AND
(*b*) NOR
(*c*) NAND
(*d*) OR

(1 min)

A7 (*d*) OR

Q8 Complete the sentence below with one of the four answers given.

'The truth table of a logic circuit shows . . .'

(*a*) *the input state for all possible combinations of output state.*
(*b*) *the number of inputs which must be at logic 1 simultaneously for the output to be at logic 1.*
(*c*) *the number of inputs necessary to obtain an output.*
(*d*) *the output state for all possible combinations of input state.*

A8 (*d*) the output state for all possible combinations of input state.

Q9 Construct two truth tables to show that

$$A.(B + C) = A.B + A.C. \qquad (5\ min)$$

A9 The truth tables for the two expressions are given below.

(*a*) $A.(B + C)$

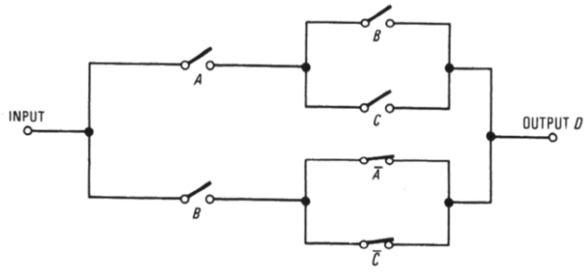
A	B	C	$B + C$	$A.(B + C)$
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	1	0
1	0	0	0	0
1	0	1	1	1
1	1	0	1	1
1	1	1	1	1

(*b*) $A.B + A.C$

A	B	C	$A.B$	$A.C$	$A.B + A.C$
0	0	0	0	0	0
0	0	1	0	0	0
0	1	0	0	0	0
0	1	1	0	0	0
1	0	0	0	0	0
1	0	1	0	1	1
1	1	0	1	0	1
1	1	1	1	1	1

The truth tables show that $A.(B + C) = A.B + A.C$

Q10 Write down the Boolean expression and derive the truth table for the switch circuit shown below. *(6 min)*



A10 The Boolean expression for the circuit can be derived as follows.
The expression for the top group of switches is $A.(B + C)$.
The expression for the bottom group of switches is $B.(\overline{A} + \overline{C})$.
The complete expression becomes

$$D = A.(B + C) + B.(\overline{A} + \overline{C}).$$

The truth table is as follows:

A	B	C	$\overline{A}$	$\overline{C}$	$B + C$	$\overline{A} + \overline{C}$	$A.(B + C)$	$B.(\overline{A} + \overline{C})$	D
0	0	0	1	1	0	1	0	0	0
0	0	1	1	0	1	1	0	0	0
0	1	0	1	1	1	1	0	1	1
0	1	1	1	0	1	1	0	1	1
1	0	0	0	1	0	1	0	0	0
1	0	1	0	0	1	0	1	0	1
1	1	0	0	1	1	1	1	1	1
1	1	1	0	0	1	0	1	0	1

Q11 What is the correct truth table for the circuit shown below, (a), (b), (c) or (d).

(*a*)

A	B	D
0	0	0
0	1	0
1	0	0
1	1	1

(*b*)

A	B	D
0	0	1
0	1	1
1	0	1
1	1	0

(*c*)

A	B	D
0	0	1
0	1	0
1	0	0
1	1	0

(*d*)

A	B	D
0	0	0
0	1	1
1	0	1
1	1	1

(2 min)

A11 (*a*)

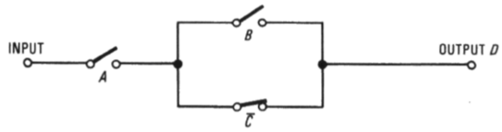
A	B	D
0	0	0
0	1	0
1	0	0
1	1	1

[*Tutorial note:* The circuit reduces to a single AND gate.]

Q12 Draw the switch circuit that has the Boolean representation

$$D = A.(B + \overline{C}). \qquad (2\ min)$$

A12



Q13 Simplify the following Boolean expressions:

(*a*) $D = A.B.C + A.B.\overline{C} + A.\overline{B}.C + A.\overline{B}$, *and*
(*b*) $D = A.(\overline{B}.\overline{C} + \overline{B}) + \overline{A}.(\overline{B} + A)$. *(6 min)*

A13 (*a*) $D = A.B.(C + \overline{C}) + A.\overline{B}.$

$= A.B + A.\overline{B},$

$= A.(B + \overline{B}),$

$= A.$

(*b*) $D = A.(\overline{B}.\overline{C} + \overline{B}) + \overline{A}.(A + \overline{B}),$

$= A.(\overline{B}) + 0 + \overline{A}.\overline{B},$

$= A.\overline{B} + \overline{A}.\overline{B},$

$= \overline{B}.$

Q14 *Draw the switch circuit that has the following truth table:*

A	B	C	D
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	1

(*7 min*)

A14 The expression for D is made up of the OR function of the following elements:

(*a*) $\overline{A}.\overline{B}.C,$

(*b*) $A.\overline{B}.C,$ and

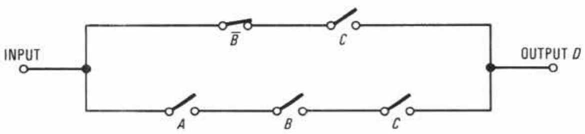
(*c*) $A.B.C.$

Thus, $D = \overline{A}.\overline{B}.C + A.\overline{B}.C + A.B.C,$

$= \overline{B}.C.(A + \overline{A}) + A.B.C,$

$= \overline{B}.C + A.B.C.$

Therefore, the switch circuit has 2 branches as shown below.



Q15 *Multiply $110\,101_2$ by 1011_2 by using binary multiplication.* (*5 min*)

A15

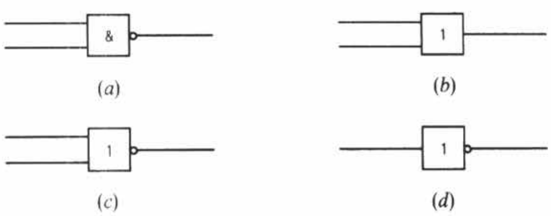
110 101	
1 011 ×	
110 101	First partial product
1 101 010	Second partial product
10 011 111	Add
110 101 000	Third partial product
1 001 000 111	Final product

Q16 *Sketch the British Standard symbols for the following logic gates:*

(*a*) NAND,
(*b*) OR,
(*c*) NOR, and
(*d*) NOT.

(*4 min*)

A16



Q17 *Perform the following calculation in binary arithmetic:*

Divide 1 101 001 by 101. (*5 min*)

A17

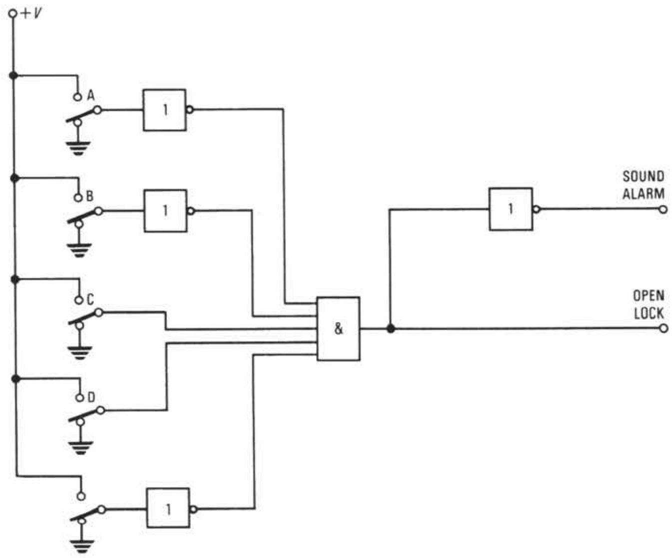
```
       10 101
101)1 101 001
    1 01
       11 0
       10 1
          101
          101
          000
```

Thus the quotient is 10 101.

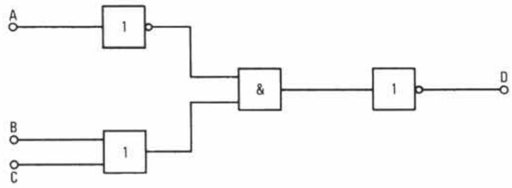
Q18 *An electronic combination lock uses a group of five 2-way switches A, B, C, D and E. The switches provide either a logic 1 or logic 0 input signal. To open the lock, the required combination is A = 0, B = 0, C = 1, D = 1 and E = 0. Any other combination sets off an alarm. Both the lock and the alarm require a logic 1 signal to operate them.*

Draw a suitable logic circuit for the lock and alarm. (*5 min*)

A18



Q19 *Produce the truth table for the logic circuit shown below.* (*5 min*)



A19

A	B	C	$\overline{A}$	$B + C$	$\overline{A}.(B + C)$	D
0	0	0	1	0	0	1
0	0	1	1	1	1	0
0	1	0	1	1	1	0
0	1	1	1	1	1	0
1	0	0	0	0	0	1
1	0	1	0	1	0	1
1	1	0	0	1	0	1
1	1	1	0	1	0	1

Q20 A 3-input logic circuit produces a logic 1 output if two or more of its inputs are at logic 1. Otherwise, it produces a logic 0. Give the truth table for the circuit and hence draw the logic diagram. (*6 min*)

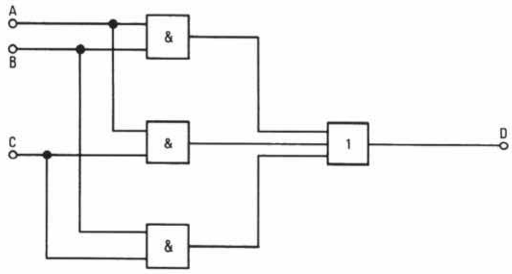
A20 The truth table is as follows:

Inputs			Output
A	*B*	*C*	*D*
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

The output can be expressed as

$$D = B.C + A.C + A.B + A.B.C.$$

Since the last term is redundant, the expression can be represented by the logic circuit shown below.



[*Tutorial note:* Other logic circuits that perform the same function can be derived by grouping the terms in the Boolean expression in different ways.]

Questions and answers contributed by D. Turner

TEC: LINES II

The questions in this paper are based on the TEC's standard unit U85/755. Students are advised to read the notes on p. 1

Q1 Compare the corporate objectives of a Government-owned national telephone network and a privately-owned national telephone network. (*4 min*)

A1 Two corporate objectives that would be common to both networks would be the provision of an efficiently engineered system and the provision of good staff relations with employees.

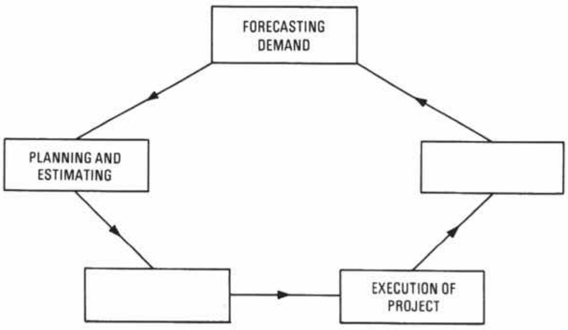
The Government-owned network would require some return on capital investments, but the level of return would be influenced by political considerations rather than the need to make a good profit. The privately-owned company would require a good return on capital investment in order to provide satisfactory earnings for the shareholders.

The Government-owned network's survival would be guaranteed by the government of the day whereas the privately-owned network would have its survival as one of its corporate objectives. A further corporate objective of the privately-owned network would be customer satisfaction, both in the day-to-day service provided and the provision of up-to-date telecommunication apparatus.

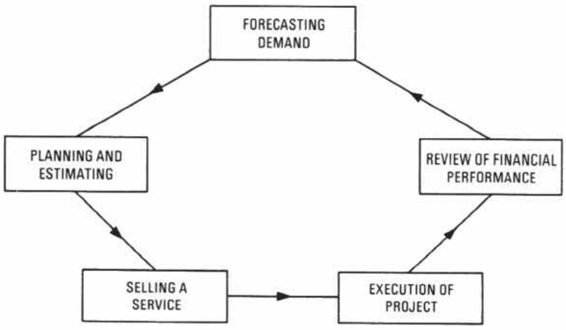
Q2 What factors influence the efficiency of a telephone transmission? (*2 min*)

A2 Influencing factors are: the signal-to-noise ratio, the frequency response of the overall transmission circuit, the level of sidetone, the level of room noise, the characteristics of the user, the level of direct current available at the transmitter.

Q3 The diagram is intended to illustrate the cycle of activities of a company. Complete the labelling of the drawing and identify the areas which are the main revenue-earning activities. (*2 min*)



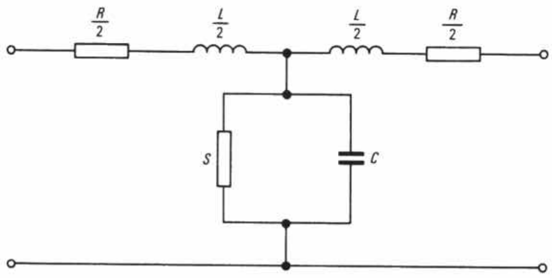
A3 The completed drawing is shown in the sketch.



Main revenue earning activities are, *selling a service* and *execution of project*.

Q4 A short length of transmission line may be represented by a T-network. Draw such a network and label all resistive and reactive components. Briefly explain what each component in your drawing represents. (*3 min*)

A4



R represents the loop resistance of the line, in ohms.
L represents the self-inductance of the line, in henrys.
C represents the capacitance between the two conductors, in farads.
S represents the losses due to insulation resistance and is expressed in terms of the conductance of the line in siemens.

Q5 *What is the main constraint to the provision of an* ideal *service to telecommunication users?* ($\frac{1}{2}$ *min*)

A5 The main contraint is the cost of providing an ideal service.

[*Tutorial note:* To provide an ideal service, all demands for service will have to be met. To provide sufficient equipment to meet all the service demands during the peak period (busiest period) of the day would result in some equipment being used for very brief periods over the period. A very poor return on the capital invested in this equipment would result. Normally, sufficient equipment is provided to meet most of the service demands during the peak period, some degradation of service quality being tolerated on economic grounds.]

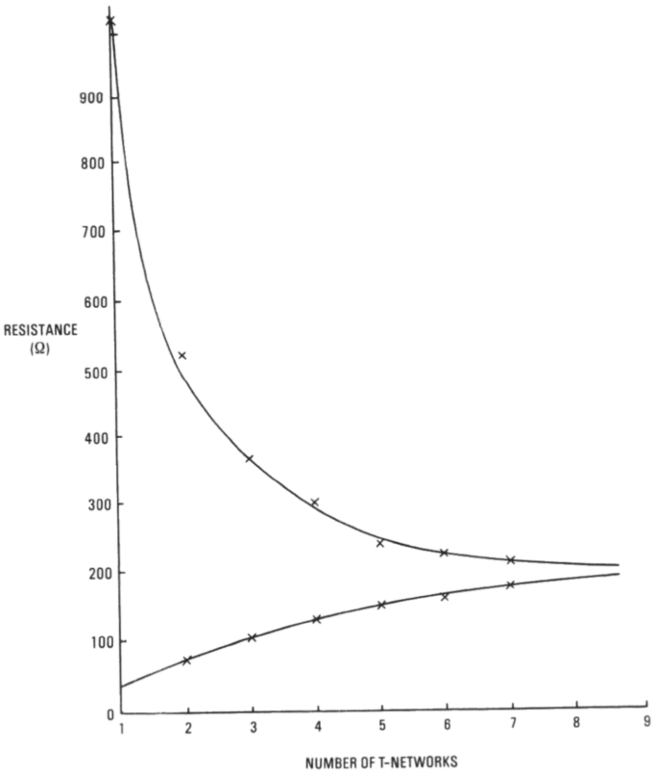
Q6 *A transmission line is divided into a number of identical T-networks. In a series of open-circuit and short-circuit tests the following data was recorded.*

Number of T-networks involved in tests	*Impedance reading of short-circuit test (ohms)*	*Impedance reading of open-circuit test (ohms)*
1	*40*	*1020*
2	*76*	*530*
3	*108*	*374*
4	*133*	*303*
5	*153*	*244*
6	*167*	*221*
7	*177*	*214*

Determine the characteristic impedance of the line. (*4 min*)

A6
Characteristic impedance of line = 200 Ω

[*Tutorial note:* The short-circuit and open-circuit results are plotted on the same scaled graph. Both curves are exponential, tending towards the 200 Ω reference level which may be taken as the characteristic-impedance value of the line.]



Q7 *State the secondary coefficients of a transmission line.* (*1 min*)

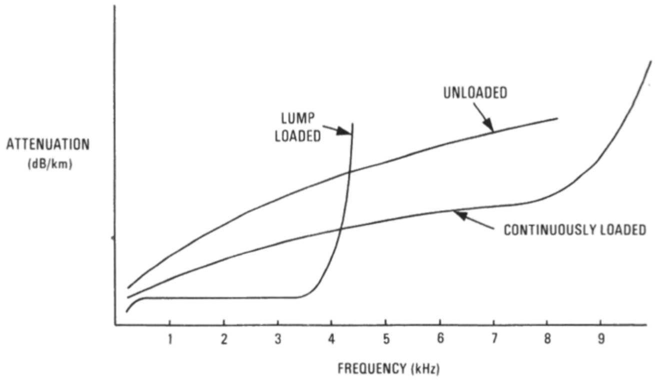
A7 Characteristic impedance; attenuation coefficient; phase change coefficient; velocity of propagation.

Q8 (*a*) *Why is it necessary to load cables?*
(*b*) *What type of loading is employed in the national network?*
(*c*) *Draw frequency response curves of the loading system(s) given in part* (*b*); *include comparative curves of unloaded cables.* (*6 min*)

A8 (*a*) The attenuation of a transmission line increases with increase in frequency. Thus, over the speech frequency range attenuation distortion occurs. To reduce the effects of attenuation distortion, additional inductance is inserted into the transmission path. This has the effect of keeping the attenuation more constant over a given frequency range. The process of adding additional inductance to a line is referred to as *loading*.

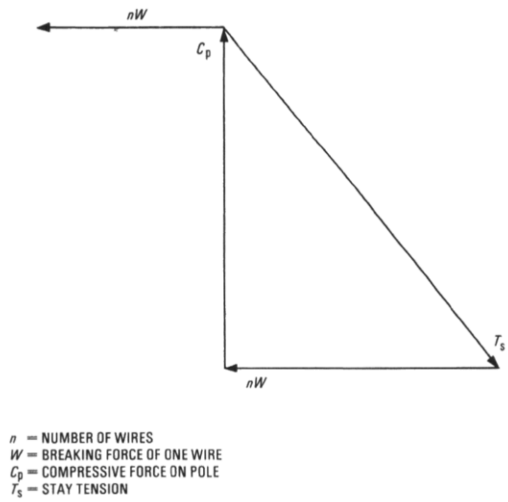
(*b*) Lumped loading and continuous loading; the former is used extensively on land lines, the latter being used only on marine links.

(*c*)

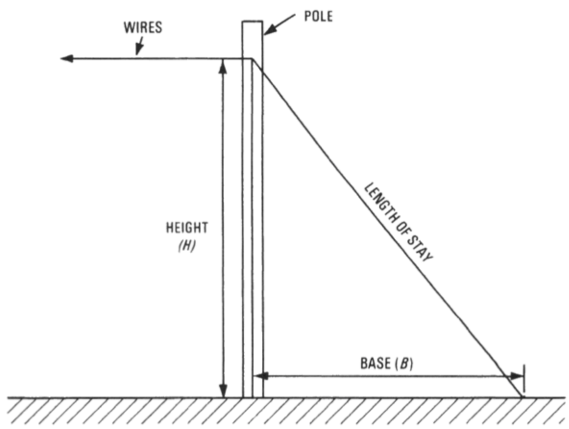


Q9 *Show, by means of a diagram, the forces on a terminal pole.*
Derive the equation for determining the stay tension of a terminal pole. (*5 min*)

A9 The triangle of forces, shown in sketch (*a*), would be identical to the triangle of lengths of the pole and stay, shown in sketch (*b*).



(*a*)



(*b*)

Thus the ratios of corresponding sides are equal and

$$\frac{nW}{B} = \frac{C_p}{H} = \frac{T_s}{\text{length of stay}},$$

But, length of stay $= \sqrt{(B^2 + H^2)}$.

$$\therefore \quad T_s = nW\left[\frac{\sqrt{(B^2 + H^2)}}{B}\right],$$

$$= nW\sqrt{\left[1 + \left(\frac{H}{B}\right)^2\right]} \text{ newtons.}$$

Q10 *What type of stay is used to resist the effects of wind pressure?* *($\frac{1}{2}$ min)*

A10 Transverse stay.

Q11 *What environmental factors affect the tension in line wires?* *($\frac{1}{2}$ min)*

A11 Temperature; ice loading on lines; wind loading on lines.

Q12 *Under ideal conditions a load-bearing pole will, under extreme stress, break at ground level. Explain why this seldom is the case in practice.* *(4 min)*

A12 Ideally a load-bearing pole has a constant diameter and is consistant in characteristic throughout its length. The mathematical proof that the breaking point is at ground level is based on the ideal conditions. In practice, the pole's diameter is not constant throughout its length and at any given point along its length, the strength of the pole is not necessarily the same as at any other point along the pole. Thus, although the pole does normally break near the ground level, the actual point of break will be determined by the weakness of any point usually up to three or four feet above ground level.

Q13 *What factors influence the resistance of a conductor?* *(2 min)*

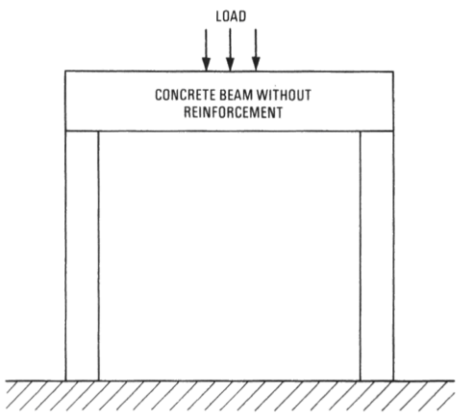
A13 Contributing factors are: the mobility of the free electrons within the conductor, the ambient temperature, the frequency of the current and the cross-sectional area of the conductor.

Q14 *When would the use of platinum contacts be preferred to that of silver contacts.* *(3 min)*

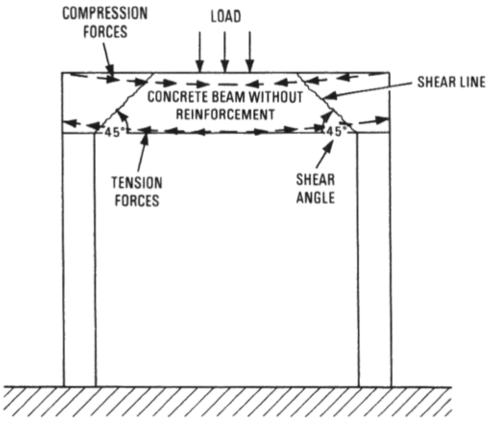
A14 When current-carrying contacts break, the current tends to keep flowing and, for a very short period of time as the contacts break, electrons bridge the gap between the contacts. Arcing between contacts occurs and this results in the generation of heat. The larger the flow of current, the greater the heat generated. Silver has much lower melting and boiling points than platinum; thus the latter is preferred when high current levels are used in a circuit. Platinum is also harder than silver and is the preferred material when high rates of operation are used.

Q15 *Indicate on the diagram the following:*

(a) direction of compression forces,
(b) direction of tension forces, and
(c) line, and angle, of shear. *(3 min)*



A15



Q16 *When can a conducting material be used as an insulator?* *(1 min)*

A16 When the screening of circuits from nearby electric fields is required.

[*Tutorial note:* A typical material would be copper sheeting.]

Q17 *A gang of five men erect sixteen poles in 30 h. Each completed pole erection is worth half of one work unit. If a work unit is equivalent to four manhours, determine the performance of the men and their productivity.* *(3 min)*

A17

$$\text{Performance} = \frac{\text{work done}}{\text{manhours}} = \frac{16 \times \frac{1}{2}}{5 \times 30} = \underline{0{\cdot}053 \text{ work units/manhour.}}$$

$$\text{Productivity} = \frac{\text{end product}}{\text{manhours}} = \frac{16}{30} = \underline{0{\cdot}53 \text{ poles/manhour.}}$$

Q18 *When would it be necessary to provide supervision?* *(1 min)*

A18 Supervision is necessary whenever the co-ordination of labour or supplies (or both) is required.

Q19 *For a cable installation project, what is the purpose of a field survey?* *(4 min)*

A19 Field surveys are necessary in order to confirm that office records, such as maps of the area, cable-duct plans, and town council plans, are all up-to-date. Field surveys are also necessary in establishing local prevailing conditions which are not generally included in office records such as, landscaped forecourts and car parks, large trees, slope of roadways, raised or lowered sidewalks, or any other type of local obstruction which may impede the installation of the cables.

Q20 *Why is it necessary to have a project plan for large line-plant installations?* *(5 min)*

A20 A large installation involves a number of workers, many having differing skills which will be required at different times during the installation. Heavy machinery will be required at various times; some for lifting purposes, others for digging trenches and still others for the drawing in of cables or for repairing damage to roads etc caused by the process of installation. The delivery from stores of various items of equipment will not, in many cases, be immediate. Lead-in times of weeks or months may be required for the delivery of major items, whereas minor items of equipment may be readily available.

The purpose of a project plan is to ensure the availability of specified labour, machinery and equipment at given times so as to provide a smooth programme of work during the installation period.

Q21 *A corporate objective of any major company would be the provision of good staff relations with employees. How may this be achieved?* *(5 min)*

A21 Good relations may be fostered in many ways, some of which are listed below:

(*a*) Management should be readily accessible to employees.

(*b*) Management should maintain informal contact with employees.
(*c*) Management should show a willingness to discuss labour problems with employees.
(*d*) Employees should be made aware of the good promotional prospects within the company.
(*e*) The company should provide, although not necessarily fully finance, a range of social activities for their employees outside of normal working hours.
(*f*) The provision of enhanced benefits such as, pension schemes, sickness allowances, holidays.
(*g*) The provision of enhanced working conditions such as suitable and safe working environment, protective clothing, hygienic washroom facilities, adequate canteen and car-parking facilities.
(*h*) Management should keep employees informed about company changes especially those which generate rumours of re-location, redundancies, short-time working and so forth.
(*i*) Management should display an even-handed approach towards all employees.

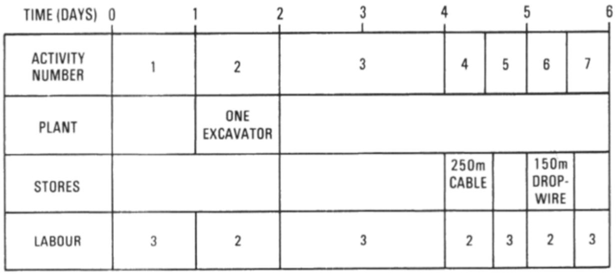
[*Tutorial note:* Level-of-earnings has not been listed as this is generally a short-term benefit in the provision of good relations!]

Q22 The table below shows the activities required to install an aerial cable. From the data, produce a suitable bar chart.

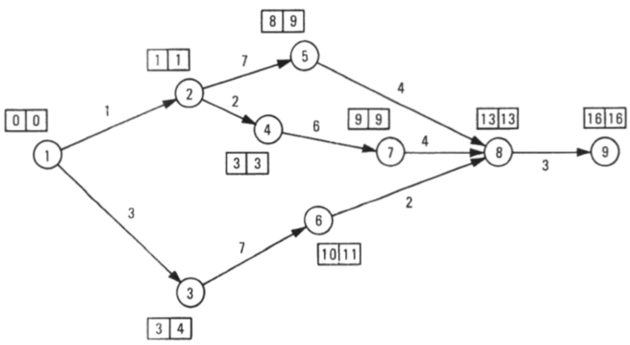
Activity Number	*Activity*	*Duration (Hours)*	*Labour*	*Plant*	*Stores*
1	*Survey route*	*2*	*3*		
2	*Dig holes*	*6*	*2*	*Excavator*	
3	*Erect poles*	*10*	*3*		*15 poles + stays*
4	*Install aerial cable*	*3*	*2*		*250 m cable*
5	*Test cable*	*1*	*3*		
6	*Install drop-wire*	*2*	*2*		*150 m dropwire*
7	*Test dropwire*	*2*	*3*		

(*4 min*)

A22

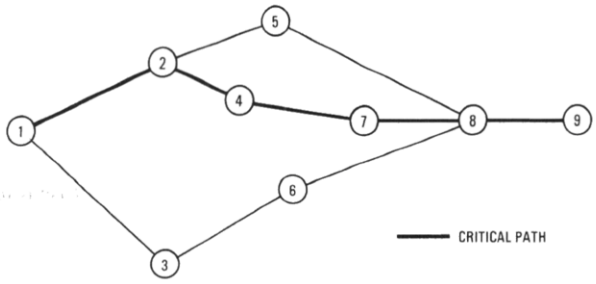


Q23 (*a*) *Identify the type of chart shown below.*



(*b*) *What do the numbers in the circles represent?*
(*c*) *What do the numbers in the squares represent?*
(*d*) *What do the numbers between circles represent?*
(*e*) *Indicate on the diagram the relevant path.* (*5 min*)

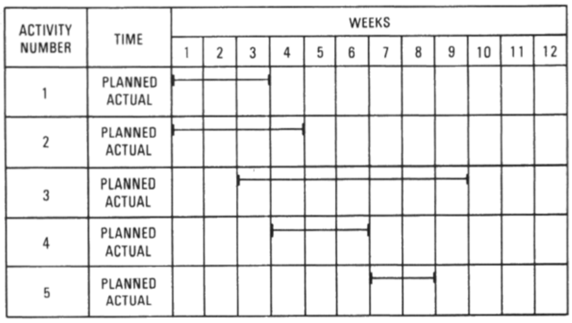
A23 (*a*) A critical path analysis (CPA) chart.
(*b*) The numbers in the circles represent the *event*. At any point within the chart the numbers of two interconnected circles represent the *activity*, the lower number being the *start* event and the higher number the *finish* event for that activity.
(*c*) The numbers in the squares represent the earliest and latest start dates for the event, the former being in the left-hand square, and the latter the right-hand square.
(*d*) The numbers between the circles indicate the duration of the activity.
(*e*)



Q24 What do the terms 'forward pass' and 'backward pass' mean in project planning? (*3 min*)

A24 *Forward pass* is the term used to describe the process of calculating the earliest date of an event.
Backward pass is the term used to describe the process of calculating the latest date of an event.

Q25



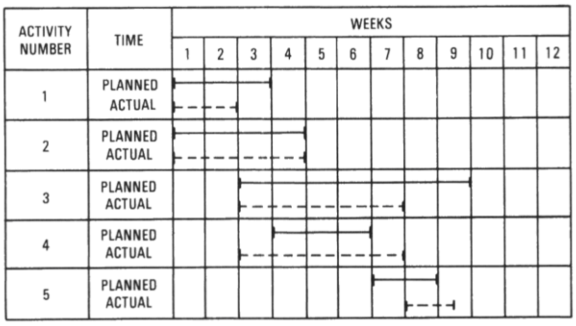
Which activities shown in the diagram give
(*a*) *a high performance,*
(*b*) *a normal performance, and*
(*c*) *a low performance,*

for the overall project, if activity 4 cannot start until activity 1 is completed, and activity 5 cannot start until activity 4 is completed.

The actual times for each activity were:
activity 1 ··· 2 weeks
activity 2 ··· 4 weeks
activity 3 ··· 5 weeks
activity 4 ··· 5 weeks
activity 5 ··· $1\frac{1}{2}$ weeks

(*d*) *Complete the chart.* (*6 min*)

A25 (*a*) Activity 1 and 3 have high project performance.
(*b*) Activity 2 and 5 have normal project performance.
(*c*) Activity 4 has low project performance.
(*d*)



Q26 State the main causes of cable faults. *(1 min)*

A26 Corrosion; sub-standard installation; damage by road-work contractors.

Q27 Distinguish between corrective maintenance and preventive maintenance. *(2 min)*

A27 Corrective maintenance is the process of clearing faults as they occur. Preventive maintenance is the process of anticipating faults before they occur and taking immediate remedial action.

Q28 A 5 km cable has an insulation resistance of 2500 MΩ. Determine the insulation resistance per kilometre and state whether this level is above the fault rated level. *(2 min)*

A28 Insulation resistance of 1 km $= 2500 \times 5$,
$= 12\,500\,\mathrm{M\Omega}$.

This value is well above the reference level of 8000 MΩ/km; thus a fault in the cable would not be suspected.

Q29 How may line faults be recognised? *(2 min)*

A29 Faults may be recognised by their effect on the values of the primary coefficients of the line and by their effect on the quality of transmission.

Q30 What type of instrument is used in the measurement of insulation resistance? *($\frac{1}{2}$ min)*

A30 A megger.

Q31 On what principle is the Varley test based? *($\frac{1}{2}$ min)*

A31 The Wheatstone bridge principle.

Q32 In a particular Varley test the following data was obtained.

Loop resistance = 850 Ω.
Varley reading = 375 Ω.
Overall length of line = 8·2 km.

Determine the distance to the fault under investigation. *(2 min)*

A32

$$\text{Distance to fault} = \left(1 - \frac{\text{Varley reading}}{\text{loop resistance}}\right) \times 8{\cdot}2\,\text{km},$$

$$= \left(1 - \frac{375}{850}\right) \times 8{\cdot}2\,\text{km}$$

$$= \underline{4{\cdot}58\,\text{km}.}$$

Q33 Why is it desirable to use pressurised cables? *(2 min)*

A33 Pressurising of cables results in a higher standard of insulation resistance being maintained, a reduction in the ingress of moisture, a means of detecting sheath faults before electrical faults occur, and a means of providing alarm signals immediately a sheath fault occurs.

Q34 Explain the term 'penetration factor'. *(2 min)*

A34 *Penetration factor* is the measure of the extent that a telephone service has been established within a given area. It is expressed as a ratio:

$$\text{PF} = \frac{\text{number of telephone connections within an area}}{\text{number of tenancies within that area}}.$$

Q35 Why is the forecasting of future requirements, for a national telephone network, desirable? *(5 min)*

A35 At any instant in time the available resources of a company must match the demand for that company's services or products. Thus it is necessary to know where and when the demand will arise and also the extent of the requirements. Furthermore, the amount of skilled labour required, lead times for stores or materials procurement and the cash-flow position all need to be known prior to the execution of a project to meet future demands. Other influencing factors may be the training of staff and the recruitment of additional staff.

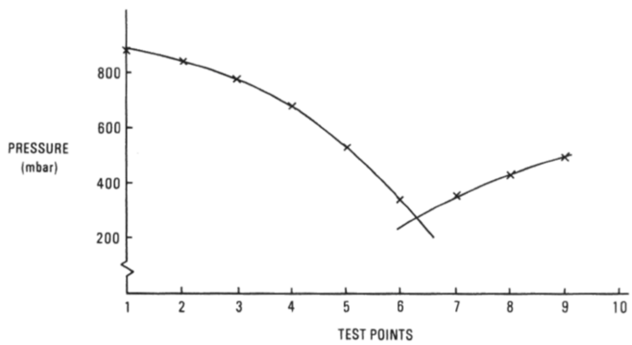
Thus forecasting allows for the provision of manpower, materials and finance as the demand for service increases. Future predictions of requirements are no guarantee of actual requirements at some future date. Nevertheless, forecasting can be fairly accurate, and timely extensions to existing plant will ensure no degradation of service; this will enhance a company's public image and lead to no loss of revenue earning capacity.

Q36 During a test to locate a leak in a pressurised cable, the following were recorded.

TP1 ··· 880 mbar	*TP2 ··· 840 mbar*	*TP3 ··· 780 mbar*
TP4 ··· 680 mbar	*TP5 ··· 540 mbar*	*TP6 ··· 340 mbar*
TP7 ··· 360 mbar	*TP8 ··· 440 mbar*	*TP9 ··· 490 mbar*

If the distance between test points is 200 m, determine the location of the fault. *(6 min)*

A36



From the graph, the fault is 60 m from TP6 going towards TP7.

Q37 What information sources are available to the local forecaster? *(2 min)*

A37 Sources available to the local forecaster are:

(*a*) the county surveyor's office,
(*b*) town planning departments,
(*c*) local architects, and
(*d*) local customers.

Q38 Distinguish between 'bottom-up' and 'top-down' forecasting. *(4 min)*

A38 Where local area forecasts are aggregated together to form a national forecast the technique is known as *bottom-up* forecasting. With this technique the forecaster has direct knowledge of local events and detailed knowledge of local geography. Also, the forecaster has close contact with the local customers. The local forecast does, however, tend to be accurate for the short term only as long-term forecasts are mainly influenced by national trends.

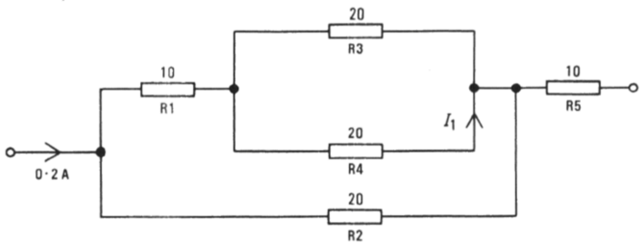
Where the national forecast figures are broken down into local area figures the technique is known as *top-down* forecasting. With this technique the forecaster has access to national leaders both in the political and business communities. Thus, first-hand knowledge of national, economic, political and technical trends are available to the forecaster. The national forecast does however tend to be accurate for the long term only, as short-term forecasts are mainly influenced by local trends.

Sometimes the two techniques are used together and the combined procedure is referred to as *complementary forecasting.*

Questions and answers contributed by N. C. Webber

The questions in the following paper are based on the TEC's standard unit number U81/747. Students are advised to read the notes on p. 1

Q1 Determine the overall resistance of the circuit shown below and the value of the current I_1. *(3 min)*



A1 Let the equivalent resistance of R3 and R4 be R_6.
Then,

$$R_6 = \frac{20 \times 20}{20 + 20} = 10\ \Omega.$$

Let the equivalent resistance of R1 and R_6 be R_7.
Then,

$$R_7 = R_1 + R_6 = 10 + 10 = 20\ \Omega.$$

Let the equivalent resistance of R2 and R_7 be R_8.
Then,

$$R_8 = \frac{20 \times 20}{20 + 20} = 10\ \Omega.$$

Let the total resistance of the circuit be R_T.

$$R_T = R_5 + R_8,$$
$$= \underline{20\ \Omega}.$$

The total current flowing is given as 0·2 A.
The current flowing in resistor R2

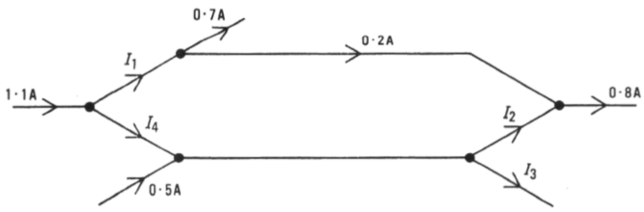
= current flowing in the upper arm of the circuit,

$= \frac{1}{2} \times 0{\cdot}2$ A.

The current flowing in resistor R3 = the current flowing in resistor R4.

$$\therefore \quad I_1 = \tfrac{1}{2} \times \tfrac{1}{2} \times 0{\cdot}2 \text{ A},$$
$$= \underline{0{\cdot}05 \text{ A}}.$$

Q2 Determine the values of I_1, I_2 and I_3, respectively, in the circuit shown below. *(2 min)*



A2

$$I_1 = 0{\cdot}7 + 0{\cdot}2 = \underline{0{\cdot}9 \text{ A}}.$$
$$I_2 = 0{\cdot}8 - 0{\cdot}2 = \underline{0{\cdot}6 \text{ A}}.$$
$$I_3 = I_4 + 0{\cdot}5 - I_2,$$
$$= 1{\cdot}1 - I_1 + 0{\cdot}5 - I_2,$$
$$= 1{\cdot}1 - 0{\cdot}9 + 0{\cdot}5 - 0{\cdot}6,$$
$$= \underline{0{\cdot}1 \text{ A}}.$$

Q3 *Complete the following statements:*

(a) Kirchoff's Law states that for any closed circuit the algebraic sum of the applied electromotive forces must be equal to the ....

(b) In a parallel-plate capacitor, as the distance between the plates increases the .... must be increased in order to keep the electric field constant.

(c) For a given material, the maximum electric field strength that the separating material between the plates of a capacitor can withstand is known as the material's ....

(d) For a parallel plate capacitor, the capacitance is directly proportional to the .... (i) ...., inversely proportional to the .... (ii) .... and depends on the .... (iii) .... material. *(2 min)*

A3 (*a*) algebraic sum of the potential differences
(*b*) applied voltage across the plates
(*c*) dielectric strength
(*d*) (*i*) cross-sectional area of the plates
(*ii*) distance between the plates
(*iii*) dielectric

Q4 A 400 pF parallel-plate capacitor consists of two plates, each 100 mm × 200 mm. If the distance between the plates is 1 mm, determine the relative permittivity of the dielectric. (Permittivity of free space = 8·85 × 10^{-12} F/m.) *(3 min)*

A4 The relative permittivity, ε_r, is given by

$$\varepsilon_r = \frac{Cd}{\varepsilon_0 A},$$

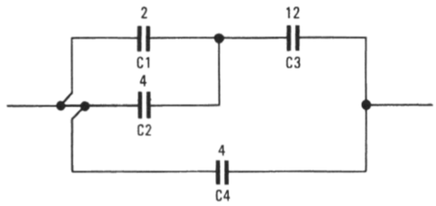
where C is the capacitance (400×10^{-12} F), d is the distance between the plates (10^{-3} m), A is the cross-sectional area (0·02 m^2), and ε_0 is the permittivity of free space ($8{\cdot}85 \times 10^{-12}$ F/m).

$$\therefore \quad \varepsilon_r = \frac{400 \times 10^{-12} \times 10^{-3}}{8{\cdot}85 \times 10^{-12} \times 0{\cdot}02},$$
$$= \underline{2{\cdot}26}.$$

Q5 Define the capacitance term 'potential gradient'. *(1 min)*

A5 *Potential gradient* is the potential fall per unit distance between two charged parallel plates.

Q6 Determine the total capacitance of the circuit shown below. *(3 min)*



A6 Let the total capacitance of C1 and C2 be C_x.
Then,

$$C_x = 2 + 4 = 6\ \mu\text{F}.$$

Let the total capacitance of C_x and C3 = C_y.
Then,

$$C_y = \frac{6 \times 12}{6 + 12} = 4\ \mu\text{F}.$$

The total capacitance of the circuit,

$$= C_y + C_4,$$
$$= \underline{8\ \mu\text{F}}.$$

Q7 What is stored in the dielectric of a capacitor? *($\frac{1}{2}$ min)*

A7 Energy.

Q8 A capacitor has a capacitance of 2 μF and a charge of 0·03 mC. Determine the energy stored. *(3 min)*

A8 The energy, W, is given by

$$W = \tfrac{1}{2}\frac{Q^2}{C},$$

where Q is the charge and C is the capacitance.

$$W = \tfrac{1}{2} \times \frac{0{\cdot}03 \times 10^{-3} \times 0{\cdot}03 \times 10^{-3}}{2 \times 10^{-6}},$$

$$= \underline{225\ \mu\text{J}.}$$

Q9 Draw a magnetisation curve using the following data obtained for a specimen of mild steel.

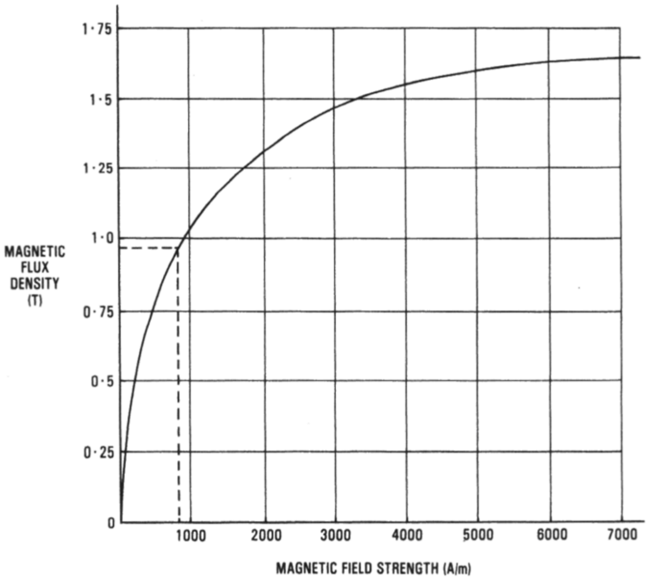
Magnetic field strength, H (A/m)	*200*	*500*	*1000*	*1500*	*2000*	*2500*
Flux density, B (T)	*0·5*	*0·8*	*1·05*	*1·2*	*1·32*	*1·4*

Magnetic field strength, H (A/m)	*3000*	*3500*	*4000*	*4500*	*5000*
Flux density, B (T)	*1·48*	*1·52*	*1·55*	*1·58*	*1·6*

Magnetic field strength, H (A/m)	*5500*	*6000*	*6500*	*7000*	*7500*
Flux density, B (T)	*1·62*	*1·63*	*1·64*	*1·65*	*1·66*

From the graph, determine the relative permeability of the material when H is 800 A/m. The permeability of free space is $4\pi \times 10^{-7}$ H/m. *(8 min)*

A9



From the graph, at $H = 800$ A/m, $B = 0{\cdot}955$ T.
The ratio $B/H = \mu_0\mu_r$, where μ_0 is the permeability of free space and μ_r is the relative permeability of the material.

$$\mu_r = \frac{B}{\mu_0 H} = \frac{0{\cdot}955}{800 \times 4\pi \times 10^{-7}},$$

$$= \underline{950.}$$

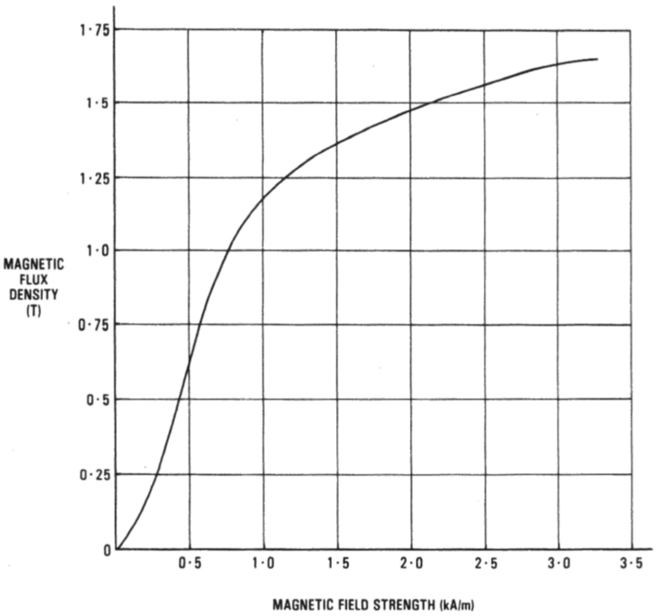
Q10 Match each type of capacitor from column A with items from column B, which refer to general applications or working levels.

Column A	*Column B*
(a) Tubular paper	*(i) Oscillator tuning*
(b) Electrolytic	*(ii) Tuning in receivers and transmitters*
(c) Air-spaced	*(iii) Miniaturised electrolytic capacitor*
(d) Polyester	*(iv) Audio-frequency coupling*
(e) Polystyrene	*(v) Tolerance range of +100% to −20%*
(f) Tantalum	*(vi) General radio-frequency purposes, up to about 80 MHz*
	(vii) Power supplies

(3 min)

A10 (*a*) (*iv*)
(*b*) (*v*), and (*vii*)
(*c*) (*ii*)
(*d*) (*vi*)
(*e*) (*i*)
(*f*) (*iii*)

Q11 A mild-steel ring of cross-sectional area 5 cm² has a radial cut of width 2 mm. If the overall length of the magnetic circuit is 62 cm, find the magnetomotive force required to cause a flux of 400 μWb in the air gap. Use the following magnetisation curve for mild steel. *(5 min)*



A11 See below for key to symbols used.

$$B = \frac{\Phi}{A} = \frac{400 \times 10^{-6}}{5 \times 10^{-4}} = 0{\cdot}8\ \text{T}.$$

From graph, $H_s = 600$ A/m at $B = 0{\cdot}8$ T.
For the mild-steel section

$$F_s = H_s L_s = 600 \times 61{\cdot}8 \times 10^{-2} = 371\ \text{A}.$$

For the air-gap section

$$F_a = H_a L_a,$$

where

$$H_a = \frac{B}{\mu_0} = \frac{0{\cdot}8}{4\pi \times 10^{-7}},$$

$$= 0{\cdot}637 \times 10^6\ \text{A/m}.$$

$$\therefore \quad F_a = 0{\cdot}637 \times 10^6 \times 0{\cdot}2 \times 10^{-2},$$

$$= 1273\ \text{A}.$$

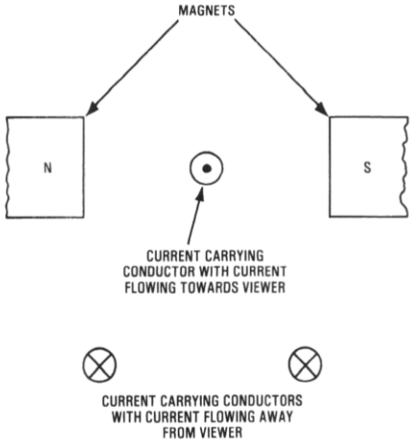
The total magnetomotive force

$$= F_s + F_a = 371 + 1273,$$

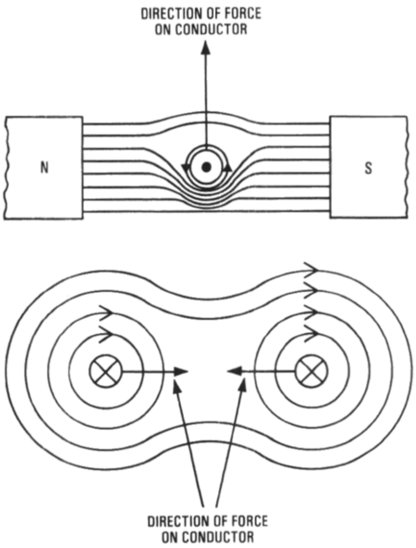
$$= \underline{1644\ \text{A}.}$$

B: Magnetic flux density
Φ: Magnetic flux
A: Cross-sectional area
H_s, H_a: Magnetic field strength for mild-steel section and air-gap section, respectively
L_s, L_a: Path length for mild-steel section and air-gap section, respectively
μ_0: Permeability of free space

Q12 *For the two diagrams shown below, sketch in the flux lines and indicate the direction of the force on the conductors.* *(2 min)*

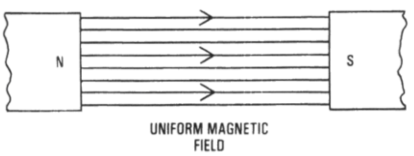


A12

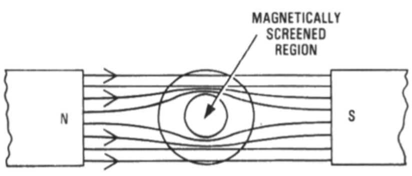


Q13 *Describe, with the aid of diagrams, how magnetic screening can be achieved.* *(5 min)*

A13 If an iron ring is placed within a uniform magnetic field (see sketch (*a*)), the region enclosed by its shape is almost devoid of magnetic flux (see sketch (*b*)). This is because the flux lines always take the path of least reluctance (resistance) and, in this case, the iron ring offers the path of least reluctance. Therefore, any component placed within the enclosed region of the ring is effectively screened from the magnetic field.



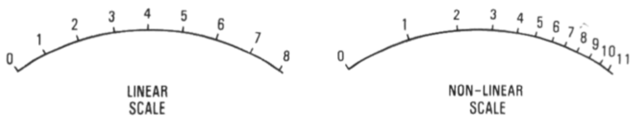
(*a*)



(*b*)

Q14 *Use sketches to illustrate the difference between linear and non-linear meter scales.* *(2 min)*

A14



Q15 *State the methods used to reduce the effects of eddy currents in transformers.* *(5 min)*

A15 Eddy currents flow in the core of the transformer. To reduce the effects of the eddy currents the core must be made of a material that offers a very high resistance to current flow and yet has a good magnetic permeability. To reduce the effects of the eddy currents the following types of cores are used: air cores, laminated cores, dust cores, and ferrite cores. Apart from the air core, these types provide good permeability and high resistance to current flow.

Q16 *Distinguish between self and mutual inductance.* *(3 min)*

A16 **Self inductance** When a current flows in a coil, it creates lines of flux around that coil. If the current value changes, the lines of flux change. If the changing lines cut the coil, an EMF is induced in the coil, its direction being such as to oppose the original change.

Mutual inductance When an EMF is induced in a coil owing to the current changing in an adjacent coil, the two circuits are said to have the property of *mutual inductance.*

Q17 *Which of the following is established first in an electrical circuit:*

(*a*) *a current, or*
(*b*) *an electromotive force?* ($\frac{1}{2}$ *min*)

A17 (*b*) an electromotive force.

[*Tutorial note:* The presence of an EMF in any circuit is not dependent on the flow of a current. A current flows in a circuit only if an EMF is present to drive that current.]

Q18 *A step-down transformer has a turns ratio of 4 : 1. If the secondary current is 2 A, determine the current in the primary coil. Assume a perfect transformer.* *(2 min)*

A18 The primary-coil current, I_p, is given by

$$I_p = I_s \times \frac{N_s}{N_p},$$

where I_s is the secondary-coil current and N_s/N_p is the turns ratio.

$$\therefore \quad I_p = 2 \times \frac{1}{4},$$

$$= \underline{0{\cdot}5\ \text{A.}}$$

Q19 *A steady current of 5 mA flows through an inductor of inductance 20 mH. Determine the energy stored in the inductor.* *(2 min)*

A19 The energy, E, is given by

$$E = \tfrac{1}{2}LI^2,$$

where L is the inductance and I is the current.

$$\therefore \quad E = \tfrac{1}{2} \times 20 \times 10^{-3} \times (5 \times 10^{-3})^2,$$

$$= \underline{0{\cdot}25\ \mu\text{J.}}$$

Q20 *Complete the following sentences.*

(*a*) *For a pure sinusoidal voltage waveform, the factors 0·637, 0·707 and 1·11 relate to the .... (i) ...., ... (ii) .... and .... (iii) .... respectively.*

(*b*) *In a series LCR circuit, when* $X_L = X_C$ *or when* $V_L = V_C$ *the circuit is said to be in ....*

(2 min)

A20 (*a*) (*i*) average value of the wave
(*ii*) RMS value of the wave
(*iii*) form factor of the wave
(*b*) resonance

Q21 *A sinusoidal voltage has a peak-to-peak value of 5·2 V and a period of 5 μs. Determine the RMS value of the wave and the frequency.* (*3 min*)

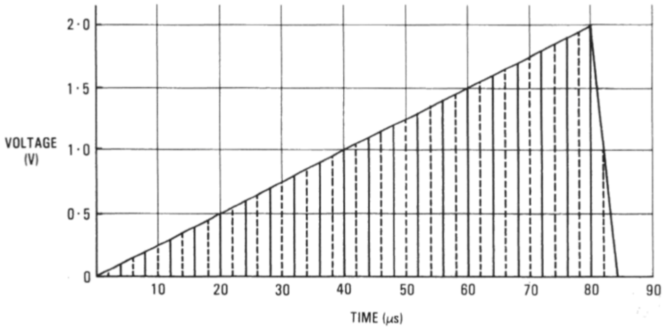
A21 The RMS value of the wave

$$= \tfrac{1}{2} \times 5{\cdot}2 \times 0{\cdot}707,$$
$$= \underline{1{\cdot}84\ \text{V}.}$$

$$\text{The frequency} = \frac{1}{\text{period}} = \frac{1}{5 \times 10^{-6}}\ \text{Hz},$$
$$= \underline{0{\cdot}2\ \text{MHz}.}$$

Q22 *A sawtooth wave rises from 0 V to 2 V in 80 μs and falls once more to 0 V in 4 μs. Determine, with the aid of a scaled diagram, the average value of each cycle.* (*8 min*)

A22 The sketch shows the waveform divided up into 21 equal sections. The mid-ordinate of each section is indicated by a dashed line.



The sum of the voltage levels of the mid-ordinates, divided by the total number of mid-ordinates gives the average value of the wave.
The sum of the voltage levels

$$= 0{\cdot}05 + 0{\cdot}15 + 0{\cdot}25 + 0{\cdot}35 + 0{\cdot}45 + \ldots \quad \ldots + 1{\cdot}95 + 1{\cdot}0,$$
$$= 21\ \text{V}.$$

Therefore the average value

$$= \frac{\text{sum of mid-ordinate voltages}}{\text{total number of mid-ordinates}} = \frac{21}{21},$$
$$= \underline{1\ \text{V}.}$$

Q23 *A resistor draws a current, $i = 24 \sin 180t$, from a supply voltage, $v = 220 \sin 180t$. Determine the power dissipated in the resistor.* (*3 min*)

A23 The power $= VI$, where V and I are the RMS values of the voltage and current, respectively.
But,

$$VI = \frac{V_{max} I_{max}}{\sqrt{2} \times \sqrt{2}},$$

where V_{max} and I_{max} are the peak values of the voltage and current, respectively.

$$\therefore \quad \text{power} = \frac{24 \times 220}{2},$$
$$= \underline{2640\ \text{W}.}$$

Q24 *An AC voltage supply having a peak-to-peak value of 40 V is applied to a bridge rectifier circuit with smoothing capacitor. Assuming no losses, what would be the approximate output voltage level of the rectifier circuit?* ($\tfrac{1}{2}$ *min*)

A24 20 V

[*Tutorial note:* The peak voltage applied to the smoothing capacitor is 20 V. As the function of the capacitor is to delay the decay of each voltage pulse, the output voltage of the circuit can be expected to be just under 20 V.]

Q25 *A capacitor of 0·1 μF is connected in descending series with an inductor of 0·36 mH. Determine the resonant frequency.* (*3 min*)

A25 The resonant frequency, f_0, is given by

$$f_0 = \frac{1}{2\pi\sqrt{(LC)}},$$

where L is the inductance and C is the capacitance.

$$\therefore \quad f_0 = \frac{1}{2\pi\sqrt{(0{\cdot}36 \times 10^{-3} \times 10^{-7})}},$$
$$= \underline{26\,526\ \text{Hz}.}$$

Q26 *A 50 kHz signal is applied to a series RL circuit having a resistance of 2500 Ω. If the phase angle is 37·2°, determine the inductance of the circuit.* (*3 min*)

A26 The tangent of the phase angle, θ, is given by

$$\tan\theta = \frac{X_L}{R},$$

where X_L is the reactance of the inductor.

$$\therefore \quad X_L = R\tan\theta = 2500 \times 0{\cdot}759,$$
$$= 1897\ \Omega.$$

But, $$X_L = 2\pi f L,$$

where f is the frequency.

$$\therefore \quad L = \frac{X_L}{2\pi f} = \frac{1897}{2\pi \times 50 \times 10^3}\ \text{H},$$
$$= \underline{6\ \text{mH}.}$$

Q27 *An induction motor is driven by a 440 V mains supply. If the current is 240 A and lags by 20°, determine*

(*a*) *the apparent power,*
(*b*) *the power factor, and*
(*c*) *the true power.* (*4 min*)

A27 (*a*) The apparent power

$$= 440 \times 240 = \underline{105{\cdot}6\ \text{kV A}.}$$

(*b*) The power factor is the cosine of the phase angle, θ,

$$= \cos\theta = \cos 20^\circ = \underline{0{\cdot}9397.}$$

(*c*) The true power = apparent power × cos θ

$$= 105{\cdot}6 \times 0{\cdot}9397\ \text{kV A} = \underline{99{\cdot}23\ \text{kV A}.}$$

Q28 *List the following in order of conductivity:*

(*a*) *aluminium,* (*b*) *silicon,* (*c*) *copper, and* (*d*) *plastic.* (*1 min*)

A28 (*c*) copper
(*a*) aluminium
(*b*) silicon
(*d*) plastic

Q29 *For each of the following statements, indicate whether a p n p or n p n transistor is implied.*

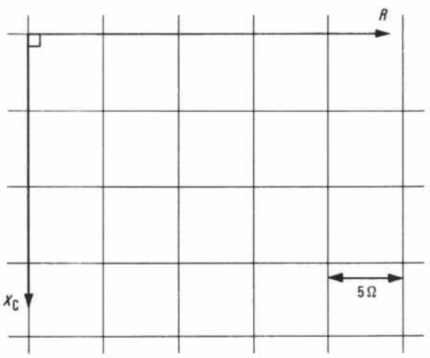
(*a*) *The base is positive with respect to the collector.*
(*b*) *The collector is negative with respect to the emitter.*
(*c*) *The base is positive with respect to the emitter.*
(*d*) *The emitter is negative with respect to the collector.* (*2 min*)

A29 (*a*) p n p
(*b*) p n p
(*c*) n p n
(*d*) n p n

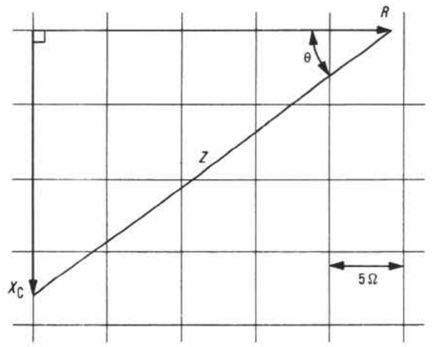
Q30 *The scaled phasor diagram of a series CR circuit relative to the resistance (R) and reactance (X_C) values is shown below.*

(a) Determine the overall impedance of the circuit.
(b) If the potential difference across the resistor is 9 V, determine the potential difference across the capacitor and the value of the supply voltage.

(4 min)



A30 The overall impedance of the circuit can be obtained by completing the impedance triangle (see sketch) and, as the drawing is to scale, the length of phasor Z gives the ohmic value of the overall impedance.



Thus,

$$Z = \underline{30\ \Omega.}$$

(*b*) The phase angle is measured directly off the scaled drawing. Thus,

$$\theta = 36{\cdot}9°.$$

If V_r is the potential difference across the resistor, then the potential difference across the capacitor

$$= V_r \tan\theta = 9 \tan 36{\cdot}9° = 6{\cdot}76 \text{ V}.$$

The supply voltage

$$= \frac{V_r}{\cos\theta} = \frac{9}{0{\cdot}8},$$

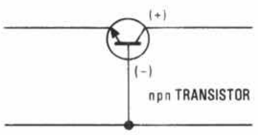
$$= \underline{11{\cdot}25 \text{ V.}}$$

Q31 *Draw a circuit diagram showing a transistor connected in*

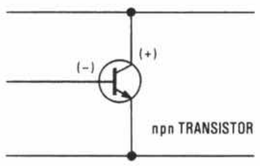
(a) common-base mode, and
(b) common-emitter mode.

In each case, show the polarity of the biasing potential of the base with respect to the collector and state whether a pnp or npn transistor has been used in your answer. *(3 min)*

A31



(*a*)



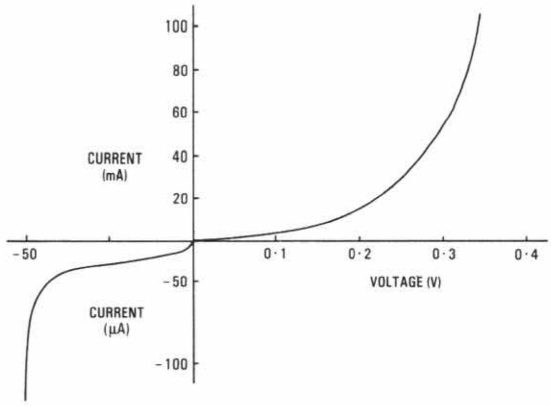
(*b*)

[*Tutorial note:* For pnp transistors, the polarities of the base and collector are reversed.]

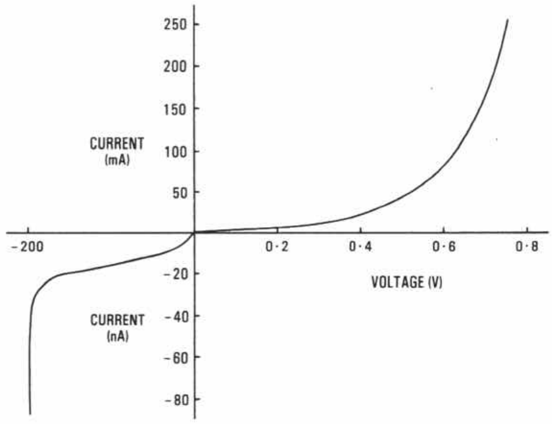
Q32 *Draw typical voltage/current characteristics for*
(a) a germanium diode, and
(b) a silicon diode.

(4 min)

A32



(*a*)



(*b*)

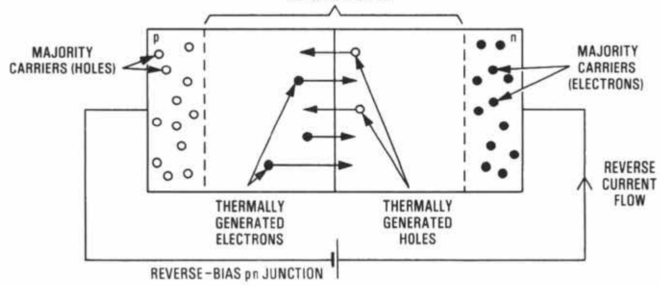
Q33 *In symbols for npn and pnp circuit symbols, what do the arrows signify?* *($\frac{1}{2}$ min)*

A33 The arrow indicates the direction of conventional current flow.

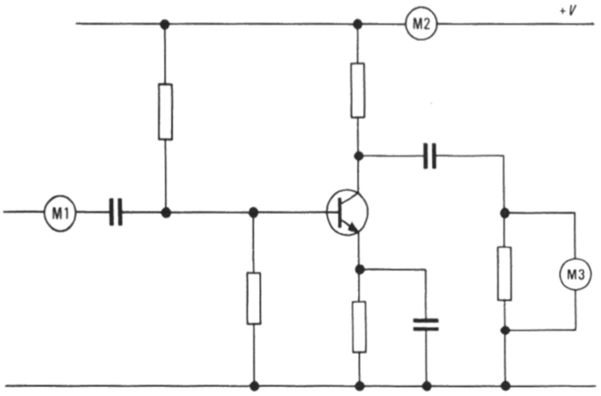
Q34 *Explain how a current flow is observed from a reverse bias pn junction.* *(6 min)*

A34 When a pn junction is reverse biased, the depletion layer is increased and no majority current carriers are able to traverse this layer (see sketch).

However, because of temperature effects, some hole/electron pairs are generated in the depletion region. As a result, free electrons in the p region flow into the n region, and free holes in the n region flow into the p region. This flow of electrons and holes constitutes a current flow and is normally referred to as the *reverse current* of the circuit.



Q35 State whether the meters in the circuit shown below are monitoring current or voltage levels. Also state if the meter is being used as a DC or AC monitor. ($1\frac{1}{2}$ *min*)



A35 M1 is monitoring current and is an AC monitor.
M2 is monitoring current and is a DC monitor.
M3 is monitoring voltage and is an AC monitor.

Q36 What is the purpose of shunts in moving-coil measuring instruments? ($\frac{1}{2}$ *min*)

A36 Shunts enable the current measuring range of the instrument to be extended.

Q37 What is meant by the term 'null method of measurement'? Give an example of its use. (*8 min*)

A37 If two points are held at the same potential and a conductor connected between them, no current will flow through the conductor.

In some methods of measurement, an unknown resistance is measured by comparison with known resistances by using the above principle. Generally four resistances are used, one unknown and three known values, one of the known resistances being of variable value. The circuit is arranged so that there are two branches, each branch comprising two resistances in series. The mid-points of the two branches are connected together via a galvanometer. When an EMF is applied across the circuit, current flows through all the branches. The variable resistance is adjusted until no current is observed flowing through the galvanometer. With the galvanometer registering zero, the circuit is said to be *at balance*, and the value of the unknown resistance can then be calculated.

The measurement technique of bringing two points up to the same potential to obtain a zero current between them is referred to as a *null method of measurement*.

[*Tutorial note:* This form of measurement is used to obtain unknown resistance, voltage and current values. The zero reading on the galvanometer is often referred to as a *null reading*. The Wheatstone bridge and potentiometer are two typical null methods of measurement.]

Q38 A moving-coil meter has a full-scale deflection when the current taken is 5 mA. Its resistance is 2 Ω. Determine the shunt resistance needed for the meter to have a measurement range of 0–50 A. (*3 min*)

A38 The maximum current to be taken by the shunt

$$= 50 - 0{\cdot}005 = 49{\cdot}995 \text{ A}.$$

The voltage across the meter and the shunt is the same.

$$\therefore \quad 0{\cdot}005 \times 2 = 49{\cdot}995 \times R_s,$$

where R_s is the shunt resistance.

$$\therefore \quad R_s = \frac{0{\cdot}005 \times 2}{49{\cdot}995},$$

$$= \underline{0{\cdot}0002\ \Omega.}$$

Q39 For a moving-coil instrument plus rectifier:

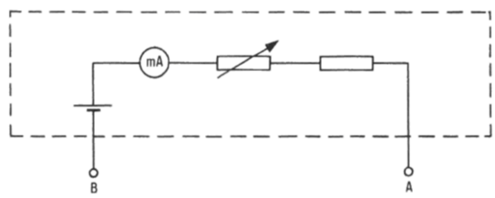
(a) Is the scale linear or non-linear?
(b) Is the frequency range of the order
(i) 0 to 400 Hz,
(ii) 20 Hz to 1 kHz,
(iii) 20 Hz to 50 kHz,
(iv) 0 to 50 kHz, or
(v) 20 Hz to 100 MHz?

(c) Does a waveform having a fundamental and third harmonic result in an incorrect reading?
(d) Is the instrument capable of accurate readings when the voltage to be measured is very low?
(e) Does it have a better frequency response than the moving-iron instrument?
(f) If the rectifier component is removed, what does the instrument read for a sinusoidal current waveform of peak value 5 mA? (*3 min*)

A39 (*a*) Linear.
(*b*) (*iii*) 20 Hz to 50 kHz.
(*c*) Yes.
(*d*) No.
(*e*) Yes.
(*f*) Zero.

[*Tutorial notes:*
For (*c*), the instrument assumes a pure sinusoidal waveform; therefore, any departure from this results in an error.
For (*d*), the rectifier itself results in some loss of voltage; thus at very small voltage levels, a fairly large error can be expected.
For (*f*), without the rectifier component, the instrument reads the average value of the current. For a sinusoidal wave, the average value is zero.]

Q40 What is the function of the fixed and variable resistors in the basic ohmmeter circuit shown below? If the value of the resistance being measured is the same as the internal resistance of the ohmmeter, where would you expect the pointer to be positioned? (*3 min*)



A40 The fixed resistor is a current limiter used to prevent instrumental damage.

The variable resistor is adjusted so that a zero resistance corresponds with full-scale deflection when the terminals of the instrument are short-circuited. This ensures accuracy of the meter reading.

If the external resistance equals the internal resistance, the pointer comes to rest in the central position of the scale.

Q41 In moving-coil instruments, what are the desirable properties of the shunt and multiplier resistors? (*1 min*)

A41 The resistors must have extremely accurate values and zero temperature coefficients. When AC is involved, the resistors must be non-inductive.

Q42 A moving-coil has a full-scale deflection of 500 μA and a resistance of 100 Ω. The meter's range is 0–1 A. Determine the power taken when the meter reads 1 A full-scale deflection. (*3 min*)

A42 The potential difference across the meter without the shunt

$$= 500 \times 10^{-6} \times 100 \text{ V} = 50 \text{ mV}.$$

$$\text{The resistance of the shunt} = \frac{50 \times 10^{-3}}{1} = 50 \times 10^{-3}\ \Omega.$$

Therefore, the power taken

$$= 1 \times 1 \times 50 \times 10^{-3} \text{ W},$$

$$= \underline{50 \text{ mW}}.$$

Questions and answers contributed by N. C. Webber

Students are advised to read the notes on p. 1

Q1 *The capacitance between two parallel wires is given by the formula*

$$C = \frac{K}{\log_e[(d-r)/r]}.$$

Calculate the value of C, correct to three decimal places, given that $K = 27{\cdot}3 \times 10^{-12}$, $d = 20$ and $r = 0{\cdot}5$. *(10 min)*

A1 Substituting in the given equation,

$$C = \frac{27{\cdot}3 \times 10^{-12}}{\log_e[(20-0{\cdot}5)/0{\cdot}5]},$$

$$= \frac{27{\cdot}3 \times 10^{-12}}{\log_e 39},$$

$$= \frac{27{\cdot}3 \times 10^{-12}}{3{\cdot}6636},$$

$$= \underline{7{\cdot}45 \times 10^{-12}}.$$

Q2 *The thermionic emission current density from a metallic surface is given by the formula*

$$J = AT^2e^{-b/T}.$$

Calculate the value of J given that $T = 2{\cdot}5 \times 10^3$, $b = 5 \times 10^4$ and $A = 4 \times 10^5$. *(10 min)*

A2 Substituting in the given equations gives

$$J = 4 \times 10^5 \times (2{\cdot}5 \times 10^3)^2 e^{-(5\times 10^4)/(2{\cdot}5\times 10^3)},$$

$$= 4 \times 10^5 \times 6{\cdot}25 \times 10^6 \times e^{-20},$$

$$= 25 \times 10^{11} \times e^{-20},$$

$$= 25 \times 10^{11} \times 2{\cdot}06 \times 10^{-9},$$

$$= 51{\cdot}5 \times 10^2 = \underline{5{\cdot}15 \times 10^3}.$$

Q3 (*a*) *Solve for x:*

$$5\log 3 - 2\log 9 + \log 27 = x\log 81.$$

(*b*) *Simplify* $\log 16 - \log 8 + 5\log 2$. *(10 min)*

A3 (*a*) $5\log 3 - 2\log 9 + \log 27 = x\log 81$.

[*Tutorial note:* $5\log 3 = \log 3^5$.]

Taking the antilog of both sides of the equation,

$$3^5/9^2 \times 27 = 81^x.$$

$$\therefore \quad 3^5/(3^2)^2 \times 3^3 = (3^4)^x.$$

$$\therefore \quad \frac{3^5 \times 3^3}{3^4} = 3^{4x}.$$

$$\therefore \quad 3^4 = 3^{4x}.$$

$$\therefore \quad 4x = 4.$$

$$\therefore \quad x = \underline{1}.$$

(*b*) $\log 16 - \log 8 + 5\log 2$

$$= \log 2^4 - \log 2^3 + \log 2^5,$$

$$= \log(2^4/2^3 \times 2^5),$$

$$= \log 2^6,$$

$$= \underline{6\log 2}.$$

Q4 *Given the equation $y = 3e^{-2x}$, tabulate values of y to an accuracy of three significant figures for values of x from -1 to $+1$ in steps of 0·25.* *(15 min)*

A4

x	-1	$-0{\cdot}75$	$-0{\cdot}5$	$-0{\cdot}25$	0	0·25	0·5	0·75	1
$2x$	-2	$-1{\cdot}5$	-1	$-0{\cdot}5$	0	0·5	1	1·5	2
$-2x$	2	1·5	1	0·5	0	$-0{\cdot}5$	-1	$-1{\cdot}5$	-2
e^{-2x}	7·39	4·48	2·72	1·65	1	0·61	0·37	0·22	0·14
$3e^{-2x}$	22·17	13·45	8·15	4·95	3	1·83	1·11	0·66	0·42

Q5 *Given that $\log_{10} 30 = 1{\cdot}4771$, without using tables, what is $\log_{10} 0{\cdot}3$? Place a tick by the correct answer.*

(*a*) *0·4771*
(*b*) *2·4771*
(*c*) $\bar{1}{\cdot}4771$
(*d*) $\bar{2}{\cdot}4771$

(2 min)

A5 (*c*) $\bar{1}{\cdot}4771$

[*Tutorial note:* $\log_{10} 30 = 1{\cdot}4771$.

Now, $30 = 3 \times 10^1$, hence the characteristic of 1. Since $0{\cdot}3 = 3 \times 10^{-1}$, the characteristic of $\log_{10} 0{\cdot}3$ is $\bar{1}$.]

Q6 *Which of the quadratic equations listed below has roots of $x = 3$ and -2. Place a tick by the correct answer.*

(*a*) $x^2 + x - 6 = 0$
(*b*) $x^2 + 3x - 2 = 0$
(*c*) $x^2 - x - 6 = 0$
(*d*) $x^2 - 3x + 2 = 0$

(5 min)

A6 (*c*) $x^2 - x - 6 = 0$

[*Tutorial note:* If $x = 3$ and -2 then the equation for x is

$$(x-3)(x+2) = 0.$$

$$\therefore \quad x^2 + 2x - 3x - 6 = 0.$$

$$x^2 - x - 6 = 0.]$$

Q7 *Factorise the following expressions:*

(*a*) $x^2 - 5x$,
(*b*) $3x^2 - 12$,
(*c*) $4x^2 + 12x + 9$, *and*
(*d*) $2x^2 + x - 6$.

(10 min)

A7 (*a*) $x^2 - 5x = \underline{x(x-5)}.$

(*b*) $3x^2 - 12 = 3(x^2 - 4),$
$= \underline{3(x-2)(x+2)}.$

(*c*) $4x^2 + 12x + 9 = (2x+3)(2x+3),$
$= \underline{(2x+3)^2}.$

(*d*) $2x^2 + x - 6 = \underline{(2x-3)(x+2)}.$

Q8 *Solve the equation $7x^2 - 3x - 8 = 0$, giving the roots correct to three decimal places.* *(15 min)*

A8 Using the formula

$$x = \frac{-b \pm \sqrt{(b^2 - 4ac)}}{2a},$$

where $a = 7$, $b = -3$, and $c = -8$, gives

$$x = \frac{3 \pm \sqrt{(9 + 224)}}{14},$$

$$= \frac{3 \pm \sqrt{233}}{14},$$

$$= \frac{3 + 15{\cdot}2643}{14} \quad \text{or} \quad \frac{3 - 15{\cdot}2643}{14},$$

$$= \frac{18{\cdot}2643}{14} \quad \text{or} \quad -\frac{12{\cdot}2643}{14},$$

$$= \underline{1{\cdot}305} \quad \text{or} \quad \underline{-0{\cdot}876}.$$

Q9 *Find the values of x and y from the equations $2x + y = 7$, and $x^2 - xy = 6$.* *(20 min)*

A9

$$2x + y = 7. \qquad \ldots\ldots (1)$$

$$x^2 - xy = 6. \qquad \ldots\ldots (2)$$

From equation 1, $y = 7 - 2x. \qquad \ldots\ldots (1a)$

Substituting for y in equation 2 gives

$$x^2 - x(7 - 2x) = 6.$$

Solving for x,

$$x^2 - 7x + 2x^2 - 6 = 0.$$

$$\therefore \quad 3x^2 - 7x - 6 = 0.$$

$$\therefore \quad (3x + 2)(x - 3) = 0.$$

$$\therefore \quad x = -\tfrac{2}{3} \text{ or } 3.$$

Substituting $x = -\frac{2}{3}$ in equation $1a$ gives

$$y = 7 + \tfrac{4}{3} = 8\tfrac{1}{3}.$$

Substituting $x = 3$ in equation $1a$ gives

$$y = 7 - 6 = 1.$$

Therefore, the solutions are

when $x = -\frac{2}{3}$, $y = 8\frac{1}{3}$; and

when $x = 3$, $y = 1$.

Check by substituting $x = -\frac{2}{3}$ and $y = 8\frac{1}{3}$ in equation 2.

$$\begin{aligned} \text{Left-hand side} &= (-\tfrac{2}{3})^2 - (-\tfrac{2}{3}) \times 8\tfrac{1}{3}, \\ &= \tfrac{4}{9} + (\tfrac{2}{3} \times \tfrac{25}{3}), \\ &= \tfrac{4}{9} + \tfrac{50}{9}, \\ &= \tfrac{54}{9}, \\ &= 6 = \text{right-hand side.} \end{aligned}$$

Therefore, $\underline{x = -\frac{2}{3},\ y = 8\frac{1}{3}}$ is a solution.

Substituting $x = 3$ and $y = 1$ in equation 2 gives

$$\begin{aligned} \text{left-hand side} &= 3^2 - (3 \times 1), \\ &= 9 - 3, \\ &= 6 = \text{right-hand side.} \end{aligned}$$

Therefore $\underline{x = 3,\ y = 1}$ is a solution.

Q10 *I spend £156 a year on telephone calls. If the price of a call goes up by 1p, I would have to make 100 fewer calls for my bill to remain the same. From the information given form a quadratic equation and calculate how many telephone calls I now make each year.* *(30 min)*

A10 Let x be the number of calls made in a year before the increase in cost. Therefore, the cost of a call was $15\,600/x$ pence.

The number of calls made after the increase in cost is $(x - 100)$. Therefore, the new cost of a call is $15\,600/(x - 100)$ pence.

$$\therefore \quad \frac{15\,600}{x - 100} = \frac{15\,600}{x} + 1.$$

Multiplying throughout by $x(x - 100)$ gives

$$\begin{aligned} 15\,600x &= 15\,600(x - 100) + x(x - 100), \\ &= 15\,600x - 1\,560\,000 + x^2 - 100x. \end{aligned}$$

$$\therefore \quad x^2 - 100x - 1\,560\,000 = 0.$$

$$\begin{aligned} \therefore \quad x &= \frac{+100 \pm \sqrt{(100^2 + 4 \times 1\,560\,000)}}{2}, \\ \therefore \quad &= \frac{100 \pm \sqrt{(10\,000 + 6\,240\,000)}}{2}, \\ &= \frac{100 \pm \sqrt{(6\,250\,000)}}{2}, \\ &= \frac{100 \pm 2500}{2}, \\ &= \frac{2600}{2} \quad \text{or} \quad -\frac{2400}{2}. \end{aligned}$$

The negative answer is discounted.

$$\therefore \quad x = 1300.$$

The number of calls that can now be made each year is

$$x - 100 = \underline{1200.}$$

Q11 *(a) State the formula to find the logarithm of a number y to base x using logarithms to base 10.*

(b) Find the value of $\log_3 5$ correct to 3 decimal places.

(c) Solve for x the following equations giving answers correct to 4 significant figures:

(i) $4^x = 7$, and

(ii) $e^{2x} = 42{\cdot}5$. *(15 min)*

A11 (*a*) $\log_y x = \dfrac{\log_{10} x}{\log_{10} y}.$

(*b*) $\log_3 5 = \dfrac{\log_{10} 5}{\log_{10} 3} = \dfrac{0{\cdot}6990}{0{\cdot}4771},$

$$= \underline{1{\cdot}465}.$$

(*c*) (*i*) $4^x = 7$.

Taking logarithms to base 10 of both sides of equation gives

$$x \log_{10} 4 = \log_{10} 7.$$

$$\begin{aligned} \therefore \quad x &= \frac{\log_{10} 7}{\log_{10} 4}, \\ &= \frac{0{\cdot}8451}{0{\cdot}6021}, \\ &= \underline{1{\cdot}404}. \end{aligned}$$

(*ii*) $e^{2x} = 42{\cdot}5$.

Taking logarithms to base e of both sides of equation gives

$$2x \log_e e = \log_e 42{\cdot}5.$$

$$\begin{aligned} \therefore \quad 2x &= \log_e 42{\cdot}5 \text{ (since } \log_e e = 1), \\ &= 3{\cdot}7495. \end{aligned}$$

$$\therefore \quad x = \underline{1{\cdot}875}.$$

Q12 *(a) Derive the instantaneous rate of change of distance (s) with respect to time (t) for the expression $s = 3t^2 - 3t$.*

(b) Calculate the rate of change when $t = 2$.

(c) Calculate the time when the rate of change is zero. *(10 min)*

A12 (*a*)

$$s = 3t^2 - 3t.$$

$$\underline{\frac{ds}{dt} = 6t - 3.}$$

(*b*) Substituting $t = 2$ in $\dfrac{ds}{dt} = 6t - 3$ gives

$$\frac{ds}{dt} = 12 - 3,$$

$$= \underline{9}.$$

(*c*) Substituting $\dfrac{ds}{dt} = 0$ in $\dfrac{ds}{dt} = 6t - 3$ gives

$$0 = 6t - 3.$$

$$\therefore \quad 6t = 3.$$

$$\therefore \quad t = \underline{\tfrac{1}{2}}.$$

Q13 *In a discharge test on a capacitor, the following results were obtained for the discharge current i after a time t:*

i	*26·5*	*21·2*	*17·3*	*14·4*	*11·5*	*9·5*
t	*0*	*40*	*80*	*120*	*160*	*200*

Plot a graph to show that the law relating i and t is of the form $i = Ie^{kt}$, and hence obtain the values of I and k. *(40 min)*

A13 To plot a straight line graph the equation $i = Ie^{kt}$ is changed to the form $y = mx + c$.

Taking logarithms to base e of both sides of the equation gives:

$$\log_e i = \log_e I + kt \log_e e.$$

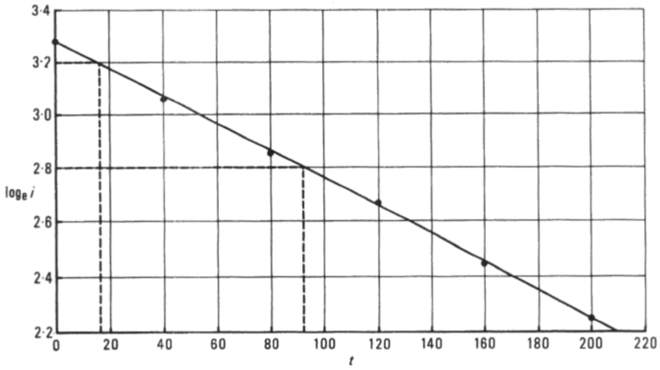
But, $\log_e e = 1$.

$$\therefore \quad \log_e i = \log_e I + kt. \qquad \ldots\ldots (1)$$

This equation is of the straight line form $y = mx + c$, where $y = \log_e I$, $mx = kt$, and $c = \log_e i$. A table of values for $\log_e i$ and t is drawn up, as follows:

$\log_e i$	3·277	3·054	2·851	2·667	2·442	2·251
t	0	40	80	120	160	200

The sketch shows these points plotted on a graph.



A straight line is a good fit to these points; therefore, the law relating i and t is of the form $\log_e i = \log_e I + kt$.

To find values of I and k

Two sets of values are selected from the graph and substituted into equation 1, to give two simultaneous equations.

From graph, when $\log_e i = 3{\cdot}2$, $t = 16$;

when $\log_e i = 2{\cdot}8$, $t = 94$.

Substituting these values in equation 1 gives:

$$3{\cdot}2 = \log_e I + 16t, \text{ and} \qquad \ldots\ldots (1a)$$

$$2{\cdot}8 = \log_e I + 94t. \qquad \ldots\ldots (1b)$$

Subtracting equation 1*b* from equation 1*a* gives

$$0{\cdot}4 = -78t.$$

$$\therefore \quad t = -\frac{0{\cdot}4}{78},$$

$$= \underline{-0{\cdot}005}.$$

Substituting $t = -0{\cdot}005$ in equation 1*a* gives

$$3{\cdot}2 = \log_e I + 16 \times (-0{\cdot}005).$$

$$\therefore \quad 3{\cdot}2 = \log_e I - 0{\cdot}080.$$

$$\therefore \quad \log_e I = 3{\cdot}2 + 0{\cdot}080,$$

$$= 3{\cdot}280.$$

$$\therefore \quad I = \underline{26{\cdot}57}.$$

Q14 *The point P(2, 4) lies on the curve $y = x^2$. Point Q$(2 + \delta x, 4 + \delta y)$ also lies on the curve.*

(a) Sketch a graph to show this information.
(b) Derive an expression for δy. *(10 min)*

A14 (*a*) See sketch.

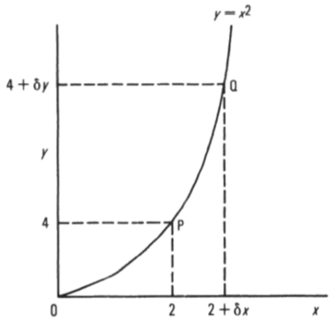
(*b*) From the equation $y = x^2$,

$$y + \delta y = (x + \delta x)^2,$$

$$= x^2 + 2x\delta x + (\delta x)^2.$$

Subtract $y = x^2$.

$$\therefore \quad \delta y = 2x\delta x + (\delta x)^2.$$



Q15 *Differentiate with respect to x from first principles $y = 3x^2$. (15 min)*

A15 From the equation $y = 3x^2$, let x increase by a small amount δx; then y will increase by a small amount δy.

$$\therefore \quad y + \delta y = 3(x + \delta x)^2,$$

$$= 3(x^2 + 2x\delta x + (\delta x)^2),$$

$$= 3x^2 + 6x\delta x + 3(\delta x)^2.$$

Subtracting $y = 3x^2$ gives

$$\delta y = 6x\delta x + 3(\delta x)^2$$

Dividing through by δx gives:

$$\frac{\delta y}{\delta x} = 6x + 3\delta x.$$

Let $\delta x \to 0$, then, in the limit, $\dfrac{\delta y}{\delta x} \to \dfrac{dy}{dx}$.

Therefore, $\dfrac{\delta y}{\delta x}$ becomes $\dfrac{dy}{dx}$, and $3\delta x$ becomes 0.

$$\therefore \quad \underline{\frac{dy}{dx} = 6x.}$$

Q16 *Differentiate the following equations with respect to x and calculate the values of those derivatives for the indicated values of x:*

(a) $y = 3x^2 - 7x - 8$, $x = 2$;

(b) $y = 11 \cos x$, $x = \dfrac{\pi}{4}$; *and*

(c) $y = \dfrac{3}{4} \cos x - \dfrac{5}{8} \sin x$, $x = \dfrac{\pi}{3}$. *(15 min)*

A16 (*a*)

$$y = 3x^2 - 7x - 8.$$

$$\therefore \quad \frac{dy}{dx} = 6x - 7.$$

When $x = 2$,

$$\frac{dy}{dx} = 12 - 7,$$

$$= \underline{5}.$$

(*b*)

$$y = 11 \cos x$$

$$\therefore \quad \frac{dy}{dx} = -11 \sin x.$$

When $x = \dfrac{\pi}{4}$,

$$\frac{dy}{dx} = -11 \sin\frac{\pi}{4},$$

$$= -11 \times 0{\cdot}7071,$$

$$= \underline{-7{\cdot}78}.$$

(*c*)

$$y = \frac{3}{4}\cos x - \frac{5}{8}\sin x.$$

$$\therefore \quad \frac{dy}{dx} = -\frac{3}{4}\sin x - \frac{5}{8}\cos x.$$

When $x = \frac{\pi}{3}$,

$$\frac{dy}{dx} = -\frac{3}{4}\sin\frac{\pi}{3} - \frac{5}{8}\cos\frac{\pi}{3},$$

$$= -\frac{3}{4} \times 0{\cdot}866 - \frac{5}{8} \times 0{\cdot}5,$$

$$= -0{\cdot}6495 - 0{\cdot}3125,$$

$$= \underline{-0{\cdot}962}.$$

Q17 *Show that an approximation for the expression*

$$\frac{\theta \tan\theta}{1-\cos\theta} \text{ is 2 when } \theta \text{ is small.}$$

(5 min)

A17 When θ is small, $\tan\theta \simeq \theta$, and

$$\cos\theta \simeq 1 - \frac{\theta^2}{2}.$$

Substituting in expression $\frac{\theta\tan\theta}{1-\cos\theta}$ gives

$$\frac{\theta \times \theta}{1 - \left(1 - \frac{\theta^2}{2}\right)},$$

$$= \frac{\theta^2}{1 - 1 + \frac{\theta^2}{2}},$$

$$= \frac{2\theta^2}{\theta^2},$$

$$= \underline{2}.$$

Q18 *Sketch the following graphs for A between 0° and 360°, stating their amplitude and period.*

(*a*) $y = 2\sin A$

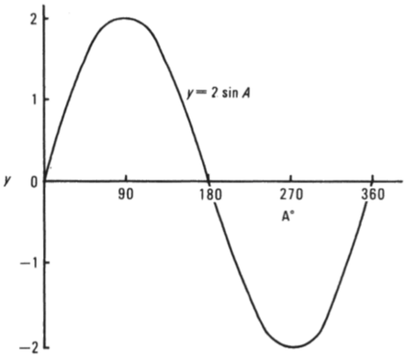
(*b*) $y = \sin\frac{A}{2}$

(*c*) $y = \cos 2A$

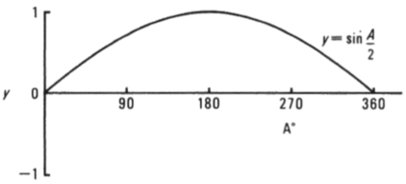
(*d*) $y = \cos^2 A$

(20 min)

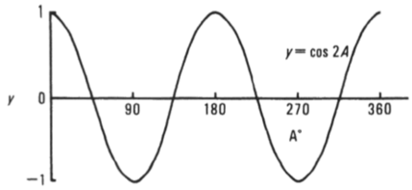
A18 (*a*) Amplitude = 2, period = 360°.



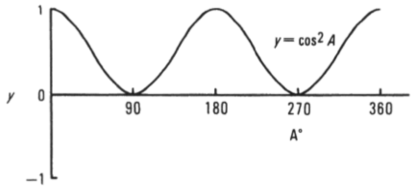
(*b*) Amplitude = 1, period = 720°.



(*c*) Amplitude = 1, period = 180°.



(*d*) Amplitude = 1, period = 180°.



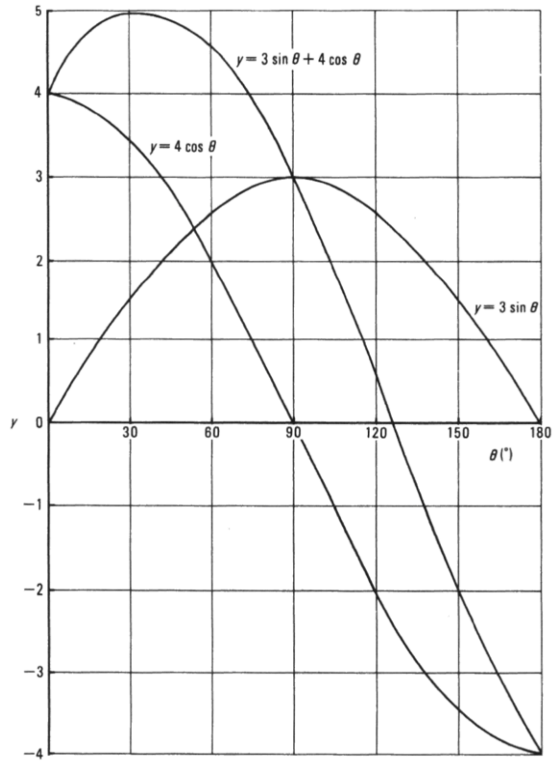
Q19 (*a*) *On the same axes and by using the same scale, draw the graphs of $y = 3\sin\theta$ and $y = 4\cos\theta$ for values of θ from 0° to 180° at intervals of 30°.*

(*b*) *By adding ordinates of the two curves, draw the resultant graph $y = 3\sin\theta + 4\cos\theta$.*

(*c*) *State the amplitude of the resultant graph.* *(45 min)*

A19 The graphs are plotted from the values in the following table:

$\theta°$	0	30	60	90	120	150	180
$\sin\theta$	0	0·5	0·866	1	0·866	0·5	1
$3\sin\theta$	0	1·5	2·598	3	2·598	1·5	0
$\cos\theta$	1	0·866	0·5	0	0·5	0·866	1
$4\cos\theta$	4	3·464	2	0	−2	−3·464	−4

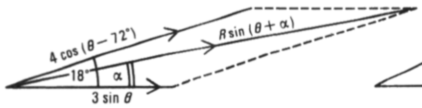


(*b*) See sketch in part (*a*).

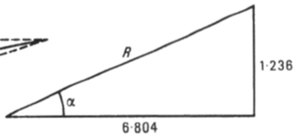
(*c*) The amplitude is 4·96.

Q20 Use a phasor method to convert $3\sin\theta + 4\cos(\theta - 72°)$ into the form $R\sin(\theta + \alpha)$. (Scale drawing will not be accepted.) *(30 min)*

A20 Phasors representing $3\sin\theta$, $4\cos(\theta - 72°)$ and $R\sin(\theta + \alpha)$ are shown in sketch (*a*).



(*a*)



(*b*)

Horizontal component of $3\sin\theta$ is 3.
Horizontal component of $4\cos(\theta - 72°)$ is $4\cos 18° = 3{\cdot}804$.
Therefore, the total horizontal component

$$= 3 + 3{\cdot}804 = 6{\cdot}804.$$

Vertical component of $3\sin\theta = 0$.
Vertical component of $4\cos(\theta - 72°)$

$$= 4\sin 18° = 1{\cdot}236.$$

Therefore, the total vertical component

$$= 0 + 1{\cdot}236 = 1{\cdot}236.$$

The vertical and horizontal components are shown in sketch (*b*). R is found by using Pythagoras' theorem.

$$\therefore \quad R = \sqrt{(6{\cdot}804^2 + 1{\cdot}236^2)},$$
$$= \sqrt{(46{\cdot}294 + 1{\cdot}528)},$$
$$= \sqrt{47{\cdot}822},$$
$$= \underline{6{\cdot}92}.$$
$$\tan\alpha = \frac{1{\cdot}236}{6{\cdot}804},$$
$$= 0{\cdot}1817.$$
$$\therefore \quad \alpha = \underline{10°\,18'}.$$

$$\therefore \quad R\sin(\theta + \alpha) \text{ is } \underline{6{\cdot}92\sin(\theta + 10°\,18')}$$

Questions and answers contributed by T. R. Sands

TEC: ELECTRONICS III

The questions in this paper are based on the TEC's standard unit U81/743. Students are advised to read the notes on p. 1

A method of assessment that is sometimes used is demonstrated by this paper. Students would be expected to answer all the 10 questions in Section A, and three out of the four questions in Section B. Students would be advised to allow 60 min for Section A and 90 min for Section B.

SECTION A

Q1 The following table gives data from DC measurements made on a transistor with the collector–emitter bias voltage (V_{CE}) held constant at 10 V.

Base–emitter voltage (V_{BE}) (V)	*Base current (I_B) (μA)*	*Collector current (I_C) (mA)*
0·628	*162*	*40·6*
0·630	*174*	*44·0*
0·632	*186*	*47·6*
0·634	*201*	*51·6*

If this transistor is to be operated with $V_{BE} = 0{\cdot}630$ V, determine:

(a) the common–emitter current gain (h_{FE}), and
(b) the small-signal common-emitter short-circuit input impedance (h_{ie}).

A1 (*a*)
$$h_{FE} = \frac{I_C}{I_B} \quad (V_{CE} \text{ constant}).$$

Therefore, when $V_{BE} = 0{\cdot}630$ V,

$$h_{FE} = \frac{44 \times 10^{-3}}{174 \times 10^{-6}},$$
$$= \underline{252{\cdot}9.}$$

(*b*)
$$h_{ie} = \frac{\Delta V_{BE}}{\Delta I_B} \quad (V_{CE} \text{ constant}),$$

where ΔV_{BE} is the change in V_{BE} that results from a small change of I_B (ΔI_B).

Therefore, when $V_{BE} = 0{\cdot}63$ V,

$$h_{ie} = \frac{0{\cdot}632 - 0{\cdot}628}{(186 - 162) \times 10^{-6}},$$
$$= \frac{0{\cdot}004}{24 \times 10^{-6}},$$
$$= \underline{166{\cdot}7\,\Omega.}$$

Q2 Comment briefly on the relative properties of a junction field-effect transistor (JUGFET) and a bipolar transistor with regard to the following:

(a) mutual conductance, and
(b) thermal stability.

A2 (*a*) The input voltage of a bipolar transistor has a much greater control of the output current than is the case with a JUGFET. This produces significantly greater values of mutual conductance for bipolar transistors, and enables much larger values of voltage gain to be achieved in bipolar-transistor amplifiers.

[*Tutorial note:* Mutual conductance, $g_m = \dfrac{\text{change in output current}}{\text{change in input voltage}}$.

Typical values of g_m for comparable operating conditions are:

bipolar transistor: 20–200 mA/V, and

JUGFET: 1–10 mA/V.]

(*b*) The collector current in bipolar transistors increases when the temperature rises. This is because of the significant increase in the minority carriers in the base and collector regions and the current-amplifying action of bipolar transistors. In JUGFETs, where the channel current is primarily due to majority carriers, the increase in charge carriers produced by a temperature rise is not so significant. The predominant effect is the increased vibration of the atoms in the channel, and this impedes the current flow. This results in a reduction in the drain current of a JUGFET when the temperature rises.

Consequently, JUGFETs have good thermal stability, whereas bipolar transistors are inherently unstable. Bipolar-transistor circuits must be designed so that the operating condition is stable.

[*Tutorial note:* Another effect of temperature in JUGFETs is the reduction in the gate-channel depletion layer as the temperature increases. This increases the drain current, but the effect is only more significant at very low values of drain current.]

Q3 State two major types of noise produced internally in amplifier circuits.

List, for each type, the variable factors upon which the amplitude of the generated noise depends.

A3 The two main types of internal noise are:

(*a*) *Thermal (or Johnson) Noise* The random motion of free electrons in a conductor produces this noise.

The noise voltage depends on:

(*i*) the resistance of the conductor (R),
(*ii*) the bandwidth of the circuit (B), and
(*iii*) the absolute temperature (T).

[*Tutorial note:* The RMS noise voltage is given by the expression

$$V_{\text{noise}} = 2\sqrt{(kRTB)} \text{ volts},$$

where k is Boltzmann's constant ($1{\cdot}38 \times 10^{-23}$ J/K).]

(*b*) *Shot noise* An electric current is the flow of discrete electric charges. Shot noise arises from statistical fluctuations in this flow.

The noise current depends on:

(*i*) the DC value of the current (I), and
(*ii*) the bandwidth of the circuit (B).

[*Tutorial note:* The RMS noise current is given by the expression

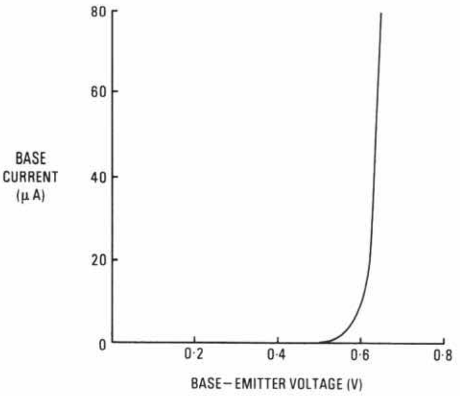
$$I_{noise} = \sqrt{(2qIB)} \quad \text{amperes,}$$

where q is the charge on an electron ($1{\cdot}6 \times 10^{-19}$ C).]

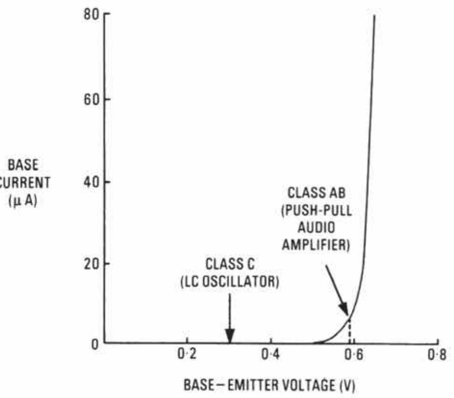
Q4 *The input characteristic of a transistor is shown below. Transistors having a similar characteristic are to be used for the following applications:*

(a) LC oscillator, and
(b) push-pull audio amplifier stage.

Indicate on the characteristic the expected operating points for these applications. State the corresponding class of bias and explain briefly your choice of operating point for both applications.



A4



(*a*) LC oscillator: class C.

The transistor would need to conduct only for a small part of the oscillatory cycle in order to replenish the energy expended by the tuned circuit. This operating condition also provides self-regulation of the output amplitude.

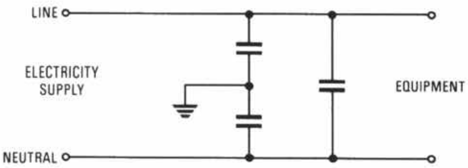
(*b*) Push-pull audio amplifier stage: class AB.

Each transistor of the push-pull pair would produce one half of the signal, the half cycles being combined in the output transformer. A small quiescent current is advisable to reduce the effect of cross-over distortion. This class of bias enables a much greater operating efficiency to be achieved.

Q5 *State two ways in which noise from electrical equipment can be propagated to receiving equipment, and, in each case, suggest how the effects of the noise can be minimised at the receiving equipment.*

A5 (*a*) Noise can reach the receiving equipment from its source by means of the mains electricity supply.

A filter in the electricity supply to the equipment would assist in minimising noise from this path. A simple capacitive filter is shown in the sketch. If this did not prove adequate, inductance could be added in series with the supply.



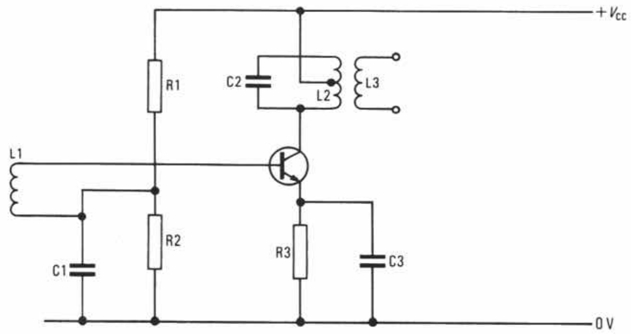
(*b*) Noise can be propagated to the receiving equipment by electromagnetic radiation from the noise source.

The following measures would help to reduce the effect of the radiated noise:

(*i*) the use of a directional aerial situated well away from possible noise sources,
(*ii*) the use of a screened feeder (coaxial cable) between aerial and receiver,
(*iii*) the magnetic and electrostatic screening of equipment to prevent direct pick-up, and
(*iv*) the use of the minimum bandwidth consistent with the requirements of the wanted signal.

Q6 *The circuit diagram shows a radio-frequency amplifier. State, with a brief explanation, which of the components fulfil the following functions:*

(a) determine operating bias, and
(b) ensure selective amplication.



A6 (*a*) The operating bias is determined by the potential divider formed by resistors R1 and R2, and the emitter resistor R3. The values of R1 and R2 determine the fixed potential applied via coil L1 to the base of the transistor. This potential, together with the value of R3, determine the no-signal emitter current.

[*Tutorial note:* Provided that the current through the potential divider R1 and R2 is much greater than the base bias current, then the base potential, V_B, is given by

$$V_B = \frac{R_2}{R_1 + R_2} \times V_{CC}.$$

Considering a silicon transistor, where the base–emitter voltage, $V_{BE} \approx 0{\cdot}6$ V, then the emitter potential, $V_E \approx V_B - 0{\cdot}6$.

Therefore, the emitter current, I_E, is given by

$$I_E \approx \frac{V_B - 0{\cdot}6}{R_3}.]$$

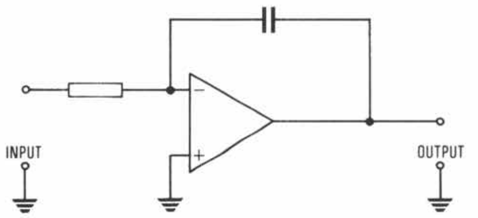
(*b*) The amplifier load is the parallel tuned circuit consisting of coil L2 and capacitor C2. The impedance of this circuit varies with frequency, the maximum impedance occuring at the resonant frequency. The gain of the amplifier is proportional to the impedance of the load; therefore, the maximum gain occurs at the resonant frequency, the amplifier being designed to operate within a narrow band of frequencies on either side of resonance.

[*Tutorial note:* The collector is connected to a tap on coil L2 to prevent the output impedance of the transistor unduly damping the selectivity of the tuned circuit.]

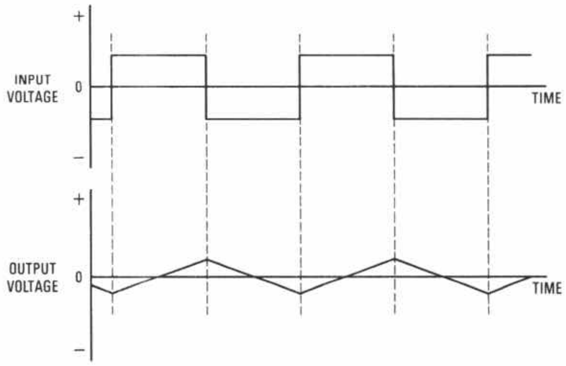
Q7 *Sketch a basic Miller integrator circuit using an operational amplifier.*

If a square wave is applied to the input, sketch the output waveform showing the relative time relationship.

A7 A Miller integrator is shown in sketch (*a*), and the input and output waveforms are shown in sketch (*b*).



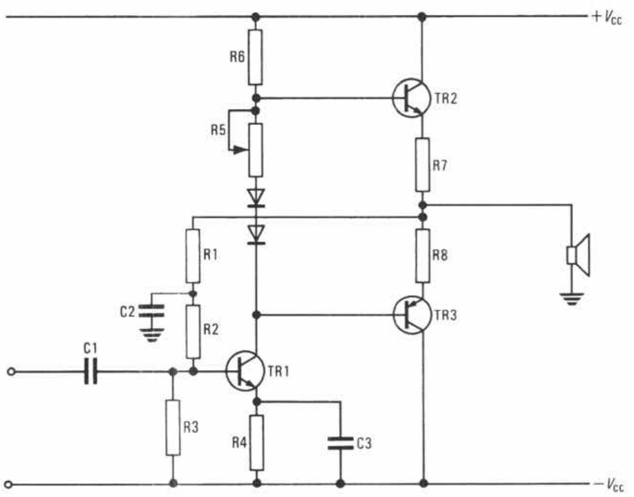
(*a*)



(*b*)

Q8 *Explain briefly the function of the following components in the audio amplifier circuit shown below:*

(*a*) *resistors R7 and R8; and*
(*b*) *resistors R1 and R2, and capacitor C2.*



A8 (*a*) Resistors R7 and R8 are small-value resistors whose function is to improve the thermal stability of the output stage. Any tendency for the collector currents of the output transistors to increase because of a rise in temperature is counteracted to some degree by the increased voltage drop across resistors R7 and R8 and the subsequent reduction in base–emitter voltages of transistors TR2 and TR3.

(*b*) Resistors R1 and R2 form a negative feedback path from the junction of resistors R7 and R8 to the base of transistor TR1. Capacitor C2 decouples this feedback path, ensuring only DC feedback. The purpose of the DC negative feedback is to maintain the quiescent voltage at the junction of resistors R7 and R8 at approximately 0 V.

[*Tutorial note:* A quiescent voltage of 0 V enables the maximum variation of signal voltage to be achieved at the output.]

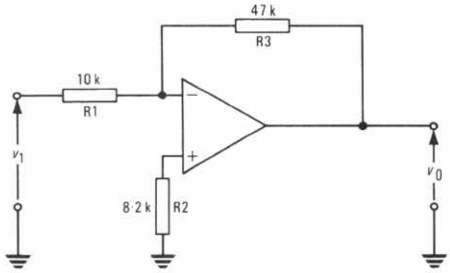
Q9 *State reasons for requiring a constant voltage output from a power supply unit.*

A9 It is important that the supply voltage is constant at the specified value in order that a reasonably predictable design may be achieved.

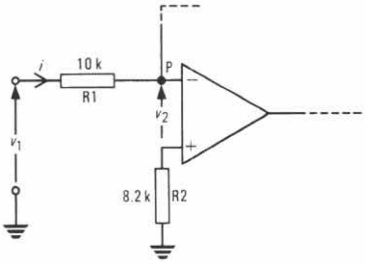
A constant supply voltage is also desirable in order to prevent unwanted feedback in multi-stage amplifiers. This can occur if substantial variations of the current drawn by the output power-amplifier stage cause variations in the supply voltage. The supply variations may be comparable with the signal amplitude in the initial stages and, so, significantly affect the performance of the amplifier.

It is imperative that any ripple voltage present on the supply is negligible. The presence of an excessive ripple voltage would result in an undesirable hum at the output of the amplifier.

Q10 *One application of an operational amplifier is shown in the circuit diagram. Determine the input resistance of this circuit. Briefly justify any assumptions made by stating examples of relevant performance characteristics.*



A10 The input circuit is shown in the sketch.



The relevant performance characteristics of the operational amplifier are:

(*a*) open loop gain = 100 dB (100 000), and
(*b*) input resistance = 2 MΩ.

The very high value of open-loop gain means that v_2 is negligible. Since the value of input resistance is very high, and v_2 is negligible, the actual current flowing into the operational amplifier, and the current flowing through resistor R2, are both negligible. Point P is therefore virtually at earth potential.

Therefore, the potential difference across resistor R1 = v_1.

$$\therefore \quad i = \frac{v_1}{R_1}.$$

The input resistance of the circuit

$$= \frac{v_1}{i} = \frac{v_1}{\dfrac{v_1}{R_1}} = R_1,$$

$$= \underline{10\,\mathrm{k}\Omega}$$

SECTION B

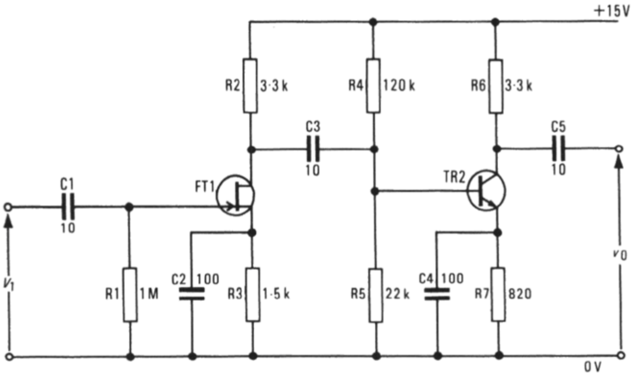
Q11 *The following data relates to the 2-stage amplifier shown below:*

FT1

Mutual conductance $(g_m) = 1{\cdot}7\,mA/V$.
Drain resistance $(r_d) = 50\,k\Omega$.

TR2

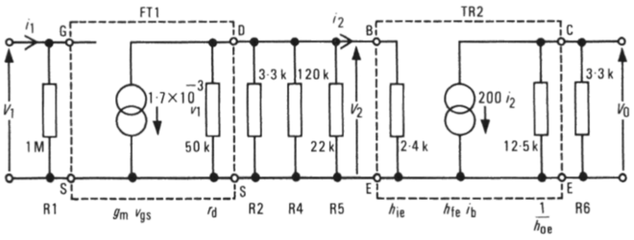
Small-signal common-emitter short-circuit input resistance $(h_{ie}) = 2{\cdot}4\,k\Omega$.
Small-signal common-emitter short-circuit current gain $(h_{fe}) = 200$.
Small-signal common-emitter open-circuit output admittance $(h_{oe}) = 80\,\mu S$.



(a) Sketch the equivalent circuit of the 2-stage amplifier at its mid-band frequencies.
(b) By using the equivalent circuit, estimate:

(i) the input resistance,
(ii) the output resistance, and
(iii) the overall voltage gain.

A11 (*a*) [*Tutorial note:* At the mid-band frequencies, the reactances of capacitors C1, C2, C3, C4 and C5 can be considered negligible. Consequently, these capacitors, together with resistors R3 and R7, do not appear in the equivalent circuit.]
The equivalent circuit is shown in the sketch.



(*b*) (*i*) The input resistance $= \dfrac{v_1}{i_1}$,

$$= \underline{1\,\text{M}\Omega}.$$

(*ii*) [*Tutorial note:* The output resistance is the resistance measured at the output terminals looking back into the amplifier, all generators being replaced by their equivalent resistance.]
Output resistance is the parallel resistance of R6 and the reciprocal of h_{oe}.

$$h_{oe} = 80\,\mu\text{S},$$
$$= 80 \times 10^{-6}\,\text{S}.$$
$$\therefore \quad \frac{1}{h_{oe}} = \frac{10^6}{80}\,\Omega,$$
$$= 12{\cdot}5\,\text{k}\Omega.$$

Therefore, the output resistance $= \dfrac{12{\cdot}5 \times 3{\cdot}3}{12{\cdot}5 + 3{\cdot}3}\,\text{k}\Omega$,

$$= \underline{2{\cdot}6\,\text{k}\Omega}.$$

(*iii*) The total load on transistor FT1, R_{T1}, is given by

$$\frac{1}{R_{T1}} = \frac{1}{r_d} + \frac{1}{R_2} + \frac{1}{R_4} + \frac{1}{R_5} + \frac{1}{h_{ie}},$$
$$= \frac{1}{50} + \frac{1}{3{\cdot}3} + \frac{1}{120} + \frac{1}{22} + \frac{1}{2{\cdot}4} \text{ (where } R_{T1} \text{ is in kilohms)},$$
$$\therefore \quad R_{T1} = 1{\cdot}26\,\text{k}\Omega.$$

The output voltage of transistor FT1,

$$v_2 = -g_m v_{gs} R_{T1},$$
$$= -1{\cdot}7 \times 10^{-3} \times v_1 \times 1{\cdot}26 \times 10^3,$$
$$= -2{\cdot}14 v_1 \text{ volts}.$$

[*Tutorial note:* The negative sign indicates that v_2 is in antiphase to v_1.]

The input current of transistor TR2,

$$i_2 = \frac{v_2}{h_{ie}},$$
$$= -\frac{2{\cdot}14\,v_1}{2{\cdot}4 \times 10^3}\,\text{A},$$
$$= -0{\cdot}89 v_1\,\text{mA}.$$

The total load, R_{T2}, on transistor TR2 is given by

$$R_{T2} = \frac{(1/h_{oe}) \times R_6}{(1/h_{oe}) + R_6},$$
$$= \frac{12{\cdot}5 \times 3{\cdot}3}{12{\cdot}5 + 3{\cdot}3}\,\text{k}\Omega,$$
$$= 2{\cdot}6\,\text{k}\Omega.$$

The output voltage of transistor TR2,

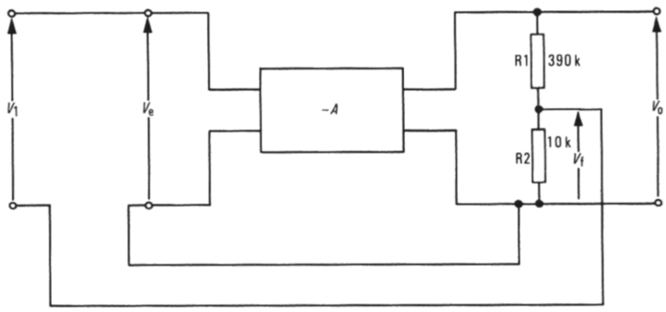
$$v_0 = -h_{fe} \times i_b \times R_{T2},$$
$$= -200 \times (-0{\cdot}89 \times 10^{-3} \times v_1) \times 2{\cdot}6 \times 10^3,$$
$$= 462{\cdot}8 v_1 \text{ volts}.$$

The overall voltage gain $= \dfrac{v_0}{v_1}$,

$$= \underline{462{\cdot}8}.$$

Q12 *(a) Define negative feedback.*
(b) An amplifier incorporating feedback is shown below. The open-loop voltage gain is $-A$.

(i) Determine the feedback fraction, and
(ii) derive an expression for the closed-loop gain of this amplifier.



(c) The results given, in the following table were obtained when this amplifier was tested under open-loop conditions.

(i) Complete the table, and
(ii) explain why the closed-loop gain shows little variation once a signal frequency of 500 Hz is reached.

Signal Frequency (Hz)	*20*	*100*	*500*	*2000*	*10 000*
Open-Loop Gain	*−16*	*−80*	*−400*	*−1569*	*−5657*
Closed-Loop Gain					

A12 (*a*) The feedback is negative when its phase is such that the effective input to the amplifier, and hence the overall gain (closed-loop gain), is reduced.

[*Tutorial note:* A closed-loop amplifier is one whose input depends upon its output.]

(*b*) (*i*) The feedback fraction, β

$$= \frac{v_f}{v_o} = \frac{R_2}{R_1 + R_2} = \frac{10}{10 + 390},$$
$$= \underline{0{\cdot}025}.$$

(*ii*) The effective input, v_e

$$= v_1 + v_f,$$
$$= v_1 + \beta v_o.$$

$$\therefore \quad v_e = v_1 + 0{\cdot}025\, v_o. \qquad \ldots\ldots (1)$$

But,

$$v_o = -A \times v_e.$$

Substitute for v_e from equation 1.

$$v_o = -A(v_1 + 0{\cdot}025\, v_o),$$
$$= -Av_1 - 0{\cdot}025Av_o.$$
$$\therefore \quad v_o + 0{\cdot}025Av_o = -Av_1.$$
$$v_o(1 + 0{\cdot}025A) = -Av_1.$$
$$\therefore \quad v_o = -\frac{Av_1}{1 + 0{\cdot}025A}.$$

The closed loop gain, A_f

$$= \frac{v_o}{v_1},$$
$$= -\frac{A}{1 + 0{\cdot}025A}. \qquad \ldots\ldots (2)$$

[*Tutorial note:* The negative sign indicates a phase change of 180° between input and output.]

(*c*) (*i*) Values of closed-loop gain to complete the table can be calculated from equation 2.

[*Tutorial note:* The open-loop gain is $-A$. When the open-loop gain is -16 (the first value given in the table), $A = 16$.

$$\therefore \quad A_F = -\frac{16}{1 + 0{\cdot}025 \times 16},$$
$$= -11{\cdot}4.]$$

Signal Frequency (Hz)	20	100	500	2000	10 000
Open-Loop Gain	−16	−80	−400	−1569	−5657
Closed-Loop Gain	−11·4	−26·7	−36·4	−39·0	−39·7

(*ii*) At frequencies of 500 Hz and higher,

$$0{\cdot}025A \gg 1.$$

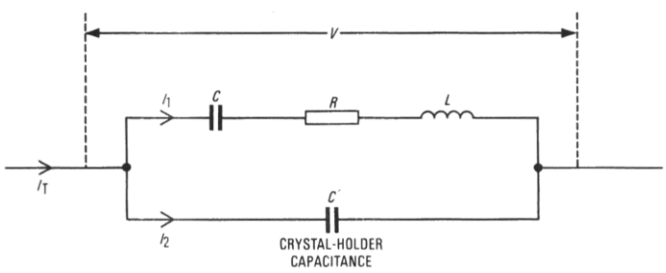
Relating this to equation 2,

$$A_F \approx -\frac{A}{0{\cdot}025A},$$
$$\approx -\frac{1}{0{\cdot}025},$$
$$\approx -40.$$

The closed-loop gain has become almost independent of the amplifier, being primarily determined by the feedback network consisting of resistors R1 and R2.

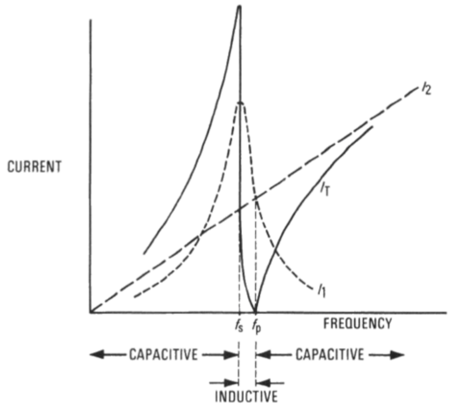
Q13 (*a*) *Explain, with the aid of diagrams, why good frequency stability is obtained in crystal oscillators.*
(*b*) *Sketch the circuit diagram of a crystal oscillator and briefly explain its action.*

A13 (*a*) As a result of the piezo-electric effect, a quartz crystal acts as a series tuned circuit having a very high Q-factor. The crystal-holder capacitance is effectively in parallel with the crystal. This combination produces the equivalent circuit shown in sketch (*a*).



(*a*)

Sketch (*b*) shows how the three currents indicated in the equivalent circuit vary with frequency.



(*b*)

Current I_1 reaches a peak value at the series resonant frequency (f_s) of the equivalent circuit, where

$$f_s = \frac{1}{2\pi\sqrt{(LC)}} \text{ hertz.}$$

At frequencies below f_s, the current I_1 leads V (the crystal behaves as a capacitive reactance). At frequencies above f_s, the current I_1 lags V (the crystal behaves as an inductive reactance).

The total current, I_T, is the phasor sum of currents I_1 and I_2 (which always leads V). Current I_T peaks at the series resonant frequency, then falls away to practically zero at the parallel resonant frequency (f_p) as I_1 and I_2 are in anti-phase.

$$f_p = \frac{1}{2\pi\sqrt{(LC_T)}} \text{ hertz, where } C_T = \frac{CC'}{C + C'} \text{ farads.}$$

The crystal behaves as an inductive reactance only between frequencies f_s and f_p.

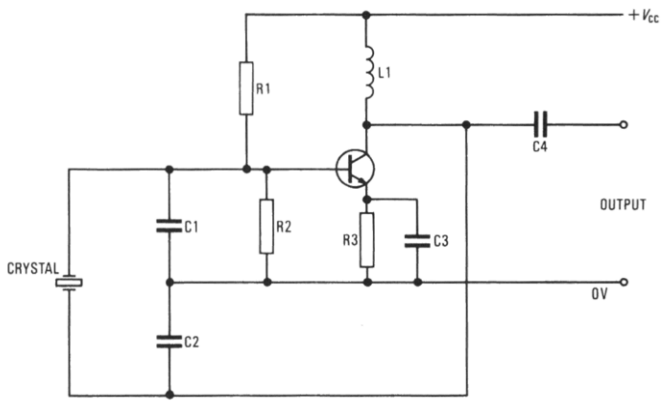
[*Tutorial note:* The crystal is inductive only when I_1 is both lagging V and greater than I_2.]

As the capacitance of the crystal holder is considerably greater than the equivalent capacitance of the crystal, the two resonant frequencies, f_s and f_p, are extremely close together. Over this very narrow frequency band, a large change occurs in the inductive reactance of the crystal.

A crystal oscillator generally operates within this narrow band. Any variation in the reactance of the oscillator circuit, possibly due to temperature or load fluctuations, is counteracted by a change in the crystal reactance in order to maintain the necessary total loop phase shift of 360°. The frequency shift required to produce the reactance change of the crystal is extremely small and thus ensures good frequency stability.

A further improvement in frequency stability can be obtained by enclosing the crystal in an oven, where the temperature is closely controlled.

(*b*) The circuit diagram of a crystal oscillator is shown in sketch (*c*).



(*c*)

The frequency of operation is determined by the crystal, which operates as an inductive reactance between its series and parallel resonant frequencies. The crystal, together with the series capacitance of capacitors C1 and C2, forms a parallel tuned circuit.

A phase shift of 180° is obtained by the transistor. The remaining 180° phase shift required is achieved by connecting the junction of

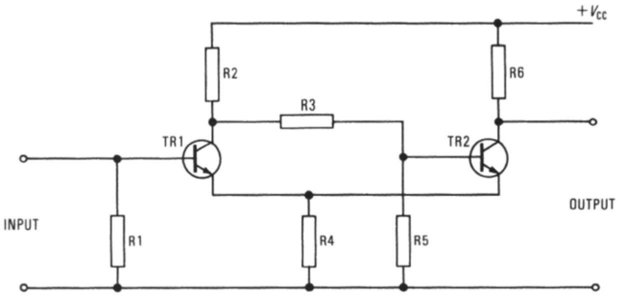
capacitors C1 and C2 via the negligible reactance of capacitor C3 to the emitter (common terminal to input and output circuits).

The inductance L1 provides a suitable impedance across which the output is developed.

Resistors R1, R2 and R3 provide the initial class-A starting bias. The class-C operating bias is obtained by resistors R1, R2 and R3, together with capacitor C3 and the rectifying action of the base–emitter junction.

Q14 Explain, with the aid of circuit and waveform diagrams, the operation of a Schmitt trigger circuit when used for reshaping pulse-type waveforms.

A14 Sketch (*a*) shows a Schmitt trigger circuit and sketch (*b*) shows the circuit waveforms.



(*a*)

When no input signal is present, transistor TR2 is conducting. The emitter current of transistor TR2 flows through resistor R4 and makes the common-emitter potential positive. The result is that transistor TR1 is cut off because of the reverse bias of its base–emitter junction.

[*Tutorial note:* The voltage at the base of transistor TR1 = 0 V, and the voltage, V_{B2}, at the base of transistor TR2 is given by

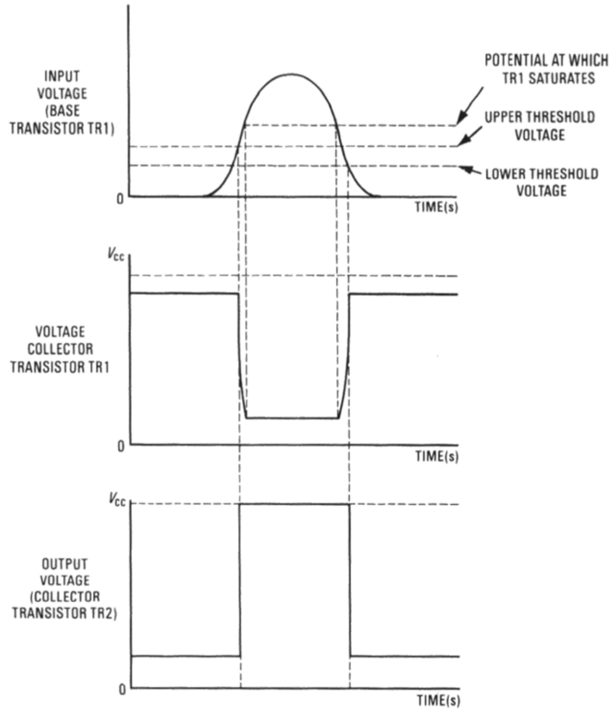
$$V_{B2} \approx \frac{R_5}{R_2 + R_3 + R_5} V_{cc}.$$

The voltage at the junction of the two emitters

$$V_E \approx V_{B2} - 0{\cdot}6 \quad \text{(assuming silicon transistors).}$$

The upper threshold voltage $\approx V_{B2}$.]

The potential required at the input to enable transistor TR1 to conduct is called the *upper threshold voltage*. When the input signal exceeds this value, transistor TR1 conducts, and this causes the collector potential and, hence, the base potential of transistor TR2 to fall. The input voltage, which continues to rise, causes the common–emitter potential to rise. The combined effect of the base potential of transistor TR2 falling and the common–emitter potential rising rapidly switches off transistor TR2, and the output voltage rises to V_{cc}. Provided the input voltage goes sufficiently positive, transistor TR1 conducts under saturation conditions.



(*b*)

The circuit remains in this state until the input voltage decreases. Once the input voltage has fallen sufficiently to shift transistor TR1 from its saturated condition, the collector current of transistor TR1 also starts to decrease. Two effects result from the reduction in collector current:

(*a*) the collector potential of transistor TR1 and, hence, the base potential of transistor TR2 rise; and

(*b*) The common–emitter potential falls owing to the reduction in the emitter current of transistor TR1.

The combination of these two effects causes the base–emitter junction of transistor TR2 to become sufficiently forward biased to enable transistor TR2 to conduct. This results in a cumulative action with transistor TR1 cutting off and transistor TR2 conducting heavily. The input potential at which this occurs is called the *lower threshold voltage*.

The difference between the two threshold voltages is called the *hysteresis* of the circuit.

The input waveform shown is a rounded pulse with substantial rise and decay times. The output waveform of the circuit is a square pulse of the desired form with extremely steep leading and trailing edges.

Questions and answers contributed by C. Wright

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